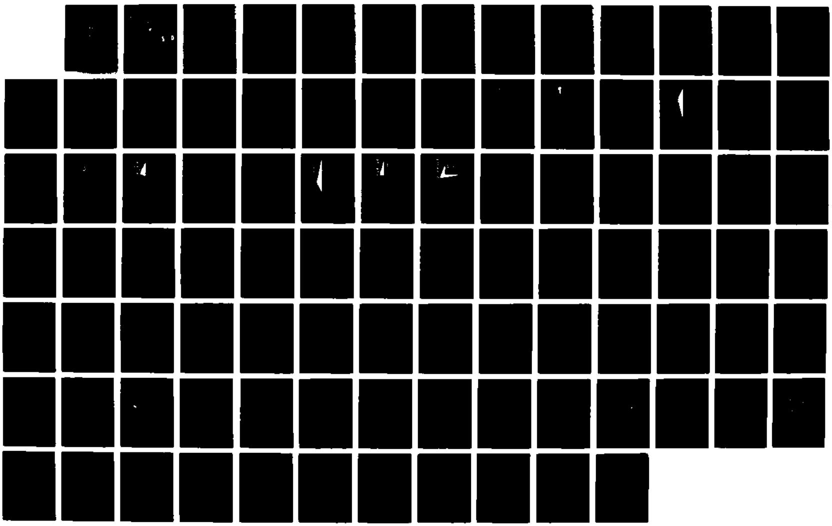
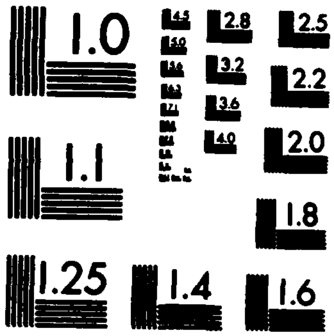
AD-A181 600 APPLICATION OF THE MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE TO A..(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA G K KRAMER MAR 87 1/1

UNCLASSIFIED F/G 25/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

APPLICATION OF THE MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE TO A STRATEGIC DEFENSE INITIATIVE COMMAND AND CONTROL SYSTEM

by

Gail K. Kramer

March 1987

Thesis Advisor Michael G. Sovereign

AD-A181 608

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) Code 74	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

APPLICATION OF THE MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE TO A STRATEGIC DEFENSE INITIATVE COMMAND AND CONTROL SYSTEM

12 PERSONAL AUTHOR(S)

Kramer, Gail K.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1987 March	92

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	SDI BM/C3; dedicated discrimination platform; MCES, BM/C3 architecture, C2 process functions

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis will focus on relating a generic evaluation structure, the Modular Command and Control Evaluation Structure (MCES) to the battle management (BM) and command, control and communication (C3) issues of the Strategic Defense Initiative (SDI). To do this, the area of SDI battle management, command and control (C2), and communications will be reviewed and explained as well as the MCES. This will provide useful descriptive analysis required for identifying and measuring proposed BM/C3 architectures. (Theses)

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Prof. Michael G. Sovereign	22b TELEPHONE (Include Area Code) (408) 646-2772 22c OFFICE SYMBOL Code 74

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Approved for public release; distribution is unlimited.

Application of the Modular Command and Control Evaluation Structure to a Strategic Defense Initiative Command and Control System

by

Gail K. Kramer
Captain, United States Air Force
B.S., United States Air Force Academy, 1982

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(Command, Control and Communications)

from the

NAVAL POSTGRADUATE SCHOOL
March 1987

Author: Gail K. Kramer

Approved by: Michael G. Sovereign, Thesis Advisor

Lois Brunner, Second Reader

M. G. Sovereign, Chairman,
Department of Command, Control and Communications

David A. Schrady,
Academic Dean

ABSTRACT

This thesis will focus on relating a generic evaluation structure, the Modular Command and Control Evaluation Structure (MCES) to the battle management (BM) and command, control and communication (C3) issues of the Strategic Defense Initiative (SDI). To do this, the area of SDI battle management, command and control (C2), and communications will be reviewed and explained as well as the MCES. This will provide useful descriptive analysis required for identifying and measuring proposed BM/C3 architectures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to offer my gratitude to the personnel at the Sandia National Laboratory, Livermore, California, Dr. Ricki Sweet and my thesis advisors. Their time and efforts has helped me through the developement of this thesis.

Sandia National Laboratory shared the concepts behind their research program of a platform manager onboard a dedicated Strategic Defense Initative platform. I used their first case study, a dedicated discriminator platform, in the application of the Modular Command and Control Evaluation Structure (MCES). I would like to offer my personal thanks to Drs. Miriam John, Larry Brandt, and Richard Wheeler for helping me define and clarify the operational concepts of the Platform Manager Program as applied to the discriminator platform.

Dr. Sweet offered many insights of the MCES which have been incorporated within this thesis. Her experience with the C2 evaluation structure helped me overcome many of the problems I encountered during this research effort.

Finally, I would like to thank my advisors, Dr. Michael Sovereign and Lois Brunner. Dr. Sovereign guided me through the MCES application, provided many insights of the potential uses of the structure and its methodology, and helped me clarify many of the issues presented in this thesis. Lois Brunner spent many hours with me discussing this research project and proof-reading the work that is finally presented in the following chapters.

I offer my sincere appreciation to everyone involved.

I. INTRODUCTION

A. OVERVIEW

This thesis will focus on relating a generic evaluation structure, the Modular Command and Control Evaluation Structure (MCES) to the battle management (BM) and command, control and communication (C3) issues of the Strategic Defense Initiative (SDI). To do this, the area of SDI battle management, command and control (C2), and communications will be reviewed and explained as well as the MCES. This will provide useful descriptive analysis required for identifying and measuring proposed BM/C3 architectures.

B. SDI BACKGROUND

In March 1983, the President called for an intensive and comprehensive effort to define a long-term research program with the ultimate goal of eliminating the threat posed by nuclear ballistic missiles. This was called the Strategic Defense Initiative (SDI) and is commonly referred to as the "Star Wars" concept. Within a year, studies concluded that powerful new technologies were becoming available that would justify major new development efforts to provide future technical options for defense against threatening nuclear ballistic missiles. In addition, a recommendation was made to initiate a broad based research effort focused on establishing the technical feasibility to permit a decision in the early 1990's on whether to proceed to system development of the SDI system. The research started immediately and is on-going today.

The Strategic Defense Initiative's prime mission is to act as a deterrent for nuclear intercontinental ballistic missiles (ICBM), medium range ballistic missile (MRBM), short range ballistic missile (SRBM), or submarine launched ballistic missile (SLBM) strikes. Through enhanced simulation models and graphic capabilities, analysts can conceptualize an attack by the Soviet Union on our cities, missile sites and/or command centers. However, the question of the most optimal SDI system and its associated BM/C3 architecture remains unanswered. As of today, there is not yet a defined SDI program stating what or where the weapons, sensors, C3 systems and supporting elements should be, nor how they should be arranged.

Efforts in the weapons research program have been pursuing two major weapon concepts: kinetic energy and directed energy weapon capabilities. Kinetic energy

weapons would include systems with the "smart" high speed kinetic kill projectile and the hyper velocity repetitive pulsed rail guns with "smart" bullets. The directed energy weapons systems may include neutral particle beams or free electron or chemical lasers. The surveillance network may be comprised of the following sensor systems: the Space Surveillance Tracking System (SSTS), Boost Surveillance Tracking System (BSTS), a new concept of an Airborne Optical Surveillance (AOS) platform or any other separate dedicated sensing systems. C3 systems would include such things as the computers and communication systems needed to operate and control the previously mentioned sensors and weapons, command facilities to house the hardware equipment and personnel. Each of these components has the advantages and disadvantages of its basing mode, whether space-based or ground-based. The space-based assets could be configured to provide effective defense during the boost, post-boost and mid-course phases of the threat trajectory. The ground-based components might be used to engage the threat during the late mid-course part of the threat trajectory and within the atmosphere at both high and low altitudes. (Appendix A describes the physical characteristics of the strategic defense problem by defining the boost, post-boost, mid-course and terminal phases.) How these components should be arranged and interact with each otner is unknown and is a major system-level issue.

The community has accepted the concept of a multi-layered defense system with each layer capable of performing independently the basic functions of threat detection, tracking, identification, weapon assignment and weapon firing. In the "Report to the Congress on the Strategic Defense Initiative", it was stressed that:

> One of our top priorities has been to examine multilayered defense architectures and define major factors affecting technology decisions, such as threats, survivability, lethality and affordability. We need to have the best understanding of these issues so that we can chart a clean course for the program. . . . the importance of the results cannot be overstated. [Ref. 1: p. II-7]

Two years into the SDI research program, a panel of reputable industry, government and academia personnel was formed, called the Eastport Study Group. They analyzed the strategic defense battle management problem and provided valuable information as well as recommendations to the SDIO BM/C3 Working Group on their approach of addressing the SDI and BM/C3 architecture problems. Parts of their report will be discussed here.

In the *Eastport Study Group Report* three fundamental criterias were identified in evaluating an SDI architecture: performance, testability and cost. [Ref. 2: p. 22]

Performance is difficult to quantify. There is no simple measure to evaluate the performance of a strategic defense architecture because the design of the system must be capable of responding to many different attack scenarios. This makes the performance measure scenario dependent. However, many experts feel that the number or fraction of warheads intercepted in an all out attack is a useful measure of performance. In addition, other properties of an architecture, such as reliability, durability, survivability and diversity may contribute to its performance.

The testablity of an architecture can be measured by the confidence with which one can determine the performance of a deployed system. Because full-scale tests are impossible, the system must be structured in a way such that its performance can be inferred accurately from small scale tests.

Last is the cost of the system. Cost is of obvious relevance and includes components such as the cost of developing, building, deploying and maintaining the system. Although the cost of building and deploying sensors and weapons is expected to dominate the cost of a deployed system, the complexity of the battle management and C2 software to control a given architecture must not be such that it could not be produced at any cost.

One of the first recommendations by the Eastport Study Group was regarding the organizational structure.

> The battle management decisions should take place in a highly decentralized framework, and that the system need not, and should not, be tightly coordinated. [Ref. 2: p. 24]

They felt that lower level tasks should be delegated to and localized within parts of a system. This formalized the "battle group" concept. A small battle group would consist of several sensors and weapon platforms that would be within a few hundred kilometers of each other and a few hundred kilometers above our missile launching area [Ref. 2: p. 24]. The components would act as a unit, comparable to soldiers fighting for the company commander, who in turn, has a chain of command for coordination purposes. The designated battle manager local to that group would combine the measurements made by the sensors in order to provide more accurate tracking of the missiles. That information would then be used by the battle

management system to assign the battle group weapons to intercept. Several battle groups as well as battle managers may be needed to protect all of the United States assets.

After one and one-half years of researching whether the SDI system should have a centralized or a decentralized hierarchy (as that recommended by the Eastport Study Group), Lieutenant General James A. Abrahamson, USAF, Director, SDIO, Office of the Secretary of Defense, declared the SDI system should be of a decentralized framework. He briefed this at the American Institute of Aeronautics and Astronautics Third National C3I Policy Issues and Answers Conference, February 3, 1987, at the Naval Postgraduate School. In addition, Lt Gen Abrahamson stated that the initial system will address the missile defense problem as a two-tier approach, unlike the Eastport Group Study recommendations of a three-tier approach. The first, and most important, is the boost/mid-course phase. The second is the late mid-course phase with possible inclusion of the terminal phase.

A project at the Sandia National Laboratories in Livermore, California, is progressing in unison with Lt Gen Abrahamson's brief. It fits into a decentralized hierarchy framework and is limited to the late mid-course phase, or the second tier of the "tier" approach. The analysts at Sandia have taken on a task of addressing a small part of an SDI BM/C3 system. They are researching the on-board computational capabilities (both software and hardware) required for the management of a SDI sensor and weapon platform. They refer to this as the "Platform Manager Program" (PMP). Specifically, they are analyzing the computational capabilities needed on-board a platform for allocating and controlling its resources and examining the autonomous (decentralized) decision-making capabilities of such a system. This "platform manager" concept is similar for a discrimination platform, where the resources would include the sensor systems onboard, as to a weapon platform, where the kill vehicles would be considered the resources. The first exemplary case chosen to address this effort is a "pop-up", sequential discriminator platform, for use in the late mid-course phase of the missile trajectory.

The discrimination platform is kept on the surface of the earth until needed and is then "popped" into space, hopefully, within range of the incoming warheads or targets. Although the analysts at Sandia National Laboratories are continuously addressing the software complication of this system, I was granted approval to identify and address some relevant command and control issues of a dedicated discrimination

platform such as this. To do this, I will apply the Modular Command and Control Evaluation Structure (MCES) to a BM/C3 system with a platform manager onboard a dedicated discrimination platform.

The MCES is a tool to assist the analyst in evaluating command and control systems and architectures. A detailed explanation of the MCES will be covered in Chapter 2, however, the next section will describe its conceptualization.

C. MCES BACKGROUND

Dr. Ricki Sweet, in her article "The Modular Command and Control Evaluation Structure (MCES) Application of and Expansion to C3 Architectural Evaluation," reported that "There is a need as well as a requirement for generic tools to evaluate C2 systems and architectures." In addition, in the article "The Expert Team of Experts Approach to C2 Organizations" Michael Athans, Massachusetts Institute of Technology, stated that:

> At the present time we do not have . . . a systematic, analytical, quantitative methodology that can be used to (1) Analyze the interactions between a fixed C2 organization and a fixed C3 system architecture, and (2) develop really meaningful and relevant measures of effectiveness. [Ref. 3]

The Organization of the Joint Chiefs of Staff (OJCS), C3S, (now OJCS/J6) recognized this lack of supporting resources for the C3 community and tasked several individuals to solve this dilemma.

In 1984, Dr. Ricki Sweet and Lt Col Thomas Fagan III, USAF, chaired a symposium to identify issues and topics that an analyst would address when evaluating a command and control (C2) system in terms of its contribution to force effectiveness. Working definitions, conceptual models, identification of measures of effectiveness, evaluation techniques and approaches, and an overall appraisal of the current status and future course of MOE analysis were topics addressed by the attendees at the symposium [Ref. 4: pp. 24-27]. Since then, a series of workshops and symposia have been held and effort has been spent to develop a general C2 evaluation methodology to determine the force effectiveness of any C2 system. This led to the development of the Modular Command and Control Evaluation Structure (MCES) Figure 1.1 displays the MCES structure.

The MCES may be viewed as:

1. A structure to direct the evaluation of C2 architectures,
2. A paradigm to select and integrate from among existing tools,

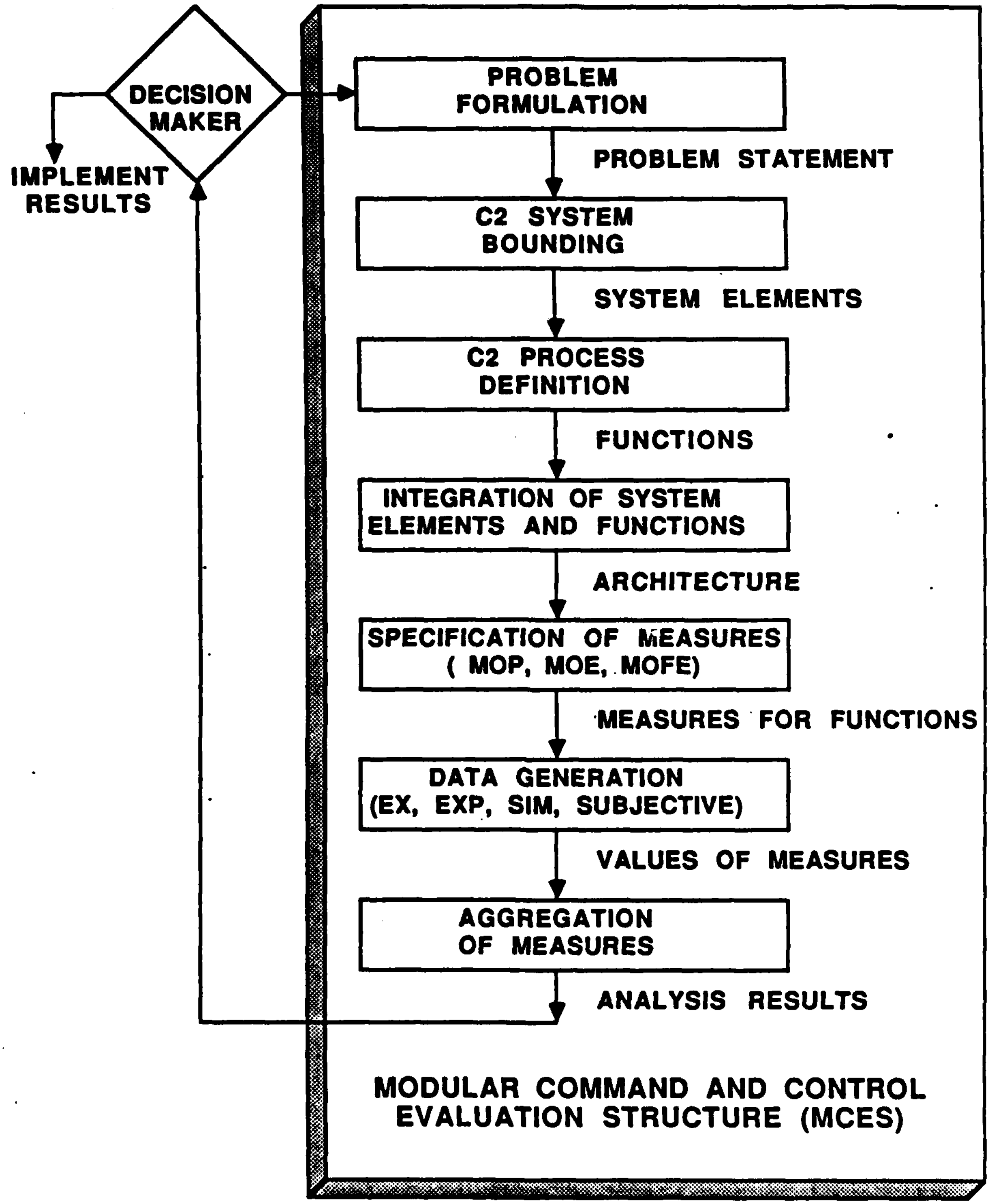


Figure 1.1 Modular Command and Control Evaluation Structure (MCES).

3. A methodology which itself may be used for evaluation,
4. Employing a common structural treatment. [Ref. 4: pp. 6-8]

The MCES has been designed to be applicable to any C2 system, to be modified or altered to fit any C2 system of interest and to evolve as new ideas and insights are presented and included.

D. APPLICATION OF MCES TO SDI

An effort at the Naval Postgraduate School (NPS) has been directed towards the application of MCES to various military command and control issues. Dr. Sweet, together with Cdr. James Offutt, USN (now retired), then SDIO, Dr. Thomas G. Rona, Office of Scientific and Technology Policy, The White House, Dr. Michael Sovereign, Chairman of the Joint C3 Academic Group, NPS, Dr. Conrad Strack, Systems Planning Corporation, Dr. Harold Glazer, The MITRE Corporation, and Dr. Mort Metersky, Naval Air Development Center (NADC), approached the problem of identifying the measures used for evaluating SDI architectures through the application of the MCES. The intent was to apply the MCES methodology to the production of developmental gains for the SDI analytical community. After learning the MCES methodology and recognizing the complexity of the BM/C3 architecture problem, I wanted to apply the MCES to a smaller well defined SDI C2 system, such as the system of the Platform Manager Project.

This thesis will apply the MCES to evaluate the discrimination platform as a part of a command and control system and address relevant issues in analyzing a BM/C3 architecture. Chapter 2 will give a brief background of the efforts of Dr. Sweet and others to develop the MCES as well as a detailed explanation of the seven modules of the MCES. The third chapter will highlight the discussions and measures identified at the SDI MCES/MOE Workshop. Chapter 4 will address the functions of the discrimination platform and its role in the SDI system while the fifth chapter will apply the MCES to the command and control process of a BM/C3 system with a dedicated discrimination platform system in a step by step manner. The sixth, and final, chapter will summarize the application of the MCES to the C2 system and the discriminator platform system.

II. MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE (MCES)

A. MCES DEVELOPMENT

A concentrated effort to develop the Modular Command and Control Evaluation Structure (MCES) methodology started in 1984 with a decision to develop a generic approach to evaluate any command and control (C2) system. "Generic", as used here, refers to a model of sufficient generality to be applicable regardless of mission area, Service, Command or C2 system. Additionally, the model would accommodate the entire C2 system, including physical entities, structure, and its environment. The objective was to develop a methodology that would address those issues to evaluate the effectiveness of a particular C2 system of interest, and wherever relevant, to relate the system to some measure of its contribution to force effectiveness.

In early 1985, the proceedings from the workshops, symposiums and personal efforts were consolidated and the MCES evolved. Through support of the OJCS/C3S, Dr. Ricki Sweet was tasked to synthesize all the work that had been done on the MCES and begin the validation of the structure by using a set of application studies.

By 1986, under the joint sponsorship of the Military Operations Research Society (MORS) and the Naval Postgraduate School (NPS), six application topics were identified and scoped to expand and test the MCES. By applying the MCES, the intent was to specifically address the problem of how to evaluate the force effectiveness of C2 systems. The individual programs are described in the subsequent sections. [Ref. 4: pp. 27-30]

1. Army Tactical Problem

The Army Tactical architectural problem posed the question "How can the SHORAD/FAAD Platoon command and control be improved to increase the number of engagements of threat aircraft?" This was presented by Major B. Galing and Major R. Wimberly of the TRADOC Research Element in Monterey, California.

2. Air Force Tactical Problem

The Air Force Tactical architectural problem centered upon the utilization of the Identification Friend, Foe, Neutral (IFFN) testbed at Kirkland Air Force Base, New Mexico, to evaluate the flow of C2 information throughout the C2 structure specific to air defense. The question addressed was "How effective is the air defense C2

system in providing decision makers the means to assess and employ air defense assets to meet overall mission objectives?" Major P. Gandee, USAF, on behalf of Colonel D. Archino, USAF, Test Director of the IFFN Test Bed, addressed this application in his research thesis (Master of Science in System Technology-C3, 1986) while attending the Naval Postgraduate School (NPS).

3. Air Force Strategic Problem

The Air Force Strategic architecture problem was to perform a mission analysis to define a concept definition for a strategic command and control system in the 2000 time frame. This was brought by Major B. Thieman of OJCS/C3S and Dr. Rona of the Office of the Secretary of Defense/DASD.

4. Navy Tactical/Battle Force Problem

The Navy Tactical/Battle Force problem was to develop architectures for battle force information systems. The architectures were to relate measures of effectiveness of command and control of a Navy anti-air warfare (AAW) system, the C2 process model and Navy functional flow diagrams and descriptions (F2D2) process. This was presented by Professor Dennis Mensh, NPS, on behalf of the Naval Surface Warfare Center.

5. Joint Tactical Problem

The Joint Tactical architectural problem centered upon the definition of measures to evaluate TADIL J communications protocol. This turned out to be two problems:

a) The comparison of implementation with protocol specifications, and

b) Given implementation, the determination of how well the TADIL J system supports required information exchanges among joint tactical data systems (TDS).

This was addressed by LT B. Nagy, USN, Naval Ocean Systems Center (NOSC).

6. Joint Strategic Problem

The Joint Strategic architectural problem centered upon the development of operations for C2 of ICBM launch detection (LD) sensors. This was brought by Dr. M. Leonardo on behalf of the Strategic Defense Initiative Office (SDIO).

Although the MCES methodology is constantly evolving to incorporate new insights, it was these six projects that initiated the testing of the theoretical approach and potential applications of the MCES. Through the direction of Dr. Sweet and the work of student teams from the NPS and individual interests, three of the projects have

been instrumental in the development of the MCES. The Air Force tactical and strategic problems and the Navy tactical/battle force problem were successful in providing vital information towards the development and evolution of the MCES. The other three were discontinued due to limited resources and sponsorship of the problems [Ref. 4: pp. 33-35]. In addition to Dr. Sweet's work, many experts in the C2 field are evaluating and/or using the MCES in their related work. Workshops and symposia are held annually to discuss the issues involved in applying the MCES methodology. All this inputs to the improvement of the MCES.

Before continuing, a detailed description of the MCES is in order to completely understand the methodology and approach behind this model.

B. MCES MODULES DESCRIPTION

The Modular Command and Control Evaluation Structure (MCES) is a tool which can assist an analyst in the evaluation of a command and control system. It is composed of seven modules and a "Decision Maker" block. See Figure 2.1 . The MCES begins with the "Problem Formulation" module and sequentially steps through to the final module, "Aggregation of Data". All the modules are important, however, the key module is "Specification of Measures". The first four modules are geared to support the development of the relevant set of measures that will be descriptive of the C2 system as a whole. The last two modules generate and aggregate the values of the identified measures. Due to the complexity of some C2 systems, multiple iterations of the entire MCES process may be required in a heirarchial fashion.

1. Module 1: Problem Formulation

The first module describes the initial step an analyst must accomplish in evaluating a C2 system, "Problem Formulation". The analyst, along with the operational user, must define the C2 problem through the development of a clear, well-defined statement of the issue or question. As a result, appropriate scenarios, analysis objectives, and the assumptions underlying the evaluation can be identified and the criteria for selecting preferred solutions should be highlighted. See Figure 2.2 .

In addition, the analyst must recognize which phase of the life cycle the C2 system is in. The life cycle of a C2 system has been segmented into three phases: concept definition, acquisition and operational. The objectives of each life cycle phase are described below. [Ref. 5: p. 6-4]

(a) Concept Definition. Develop the total system and program requirements from a broad system or mission objective. The characteristics of the system that most affect mission objectives are identified. System effectiveness analysis is

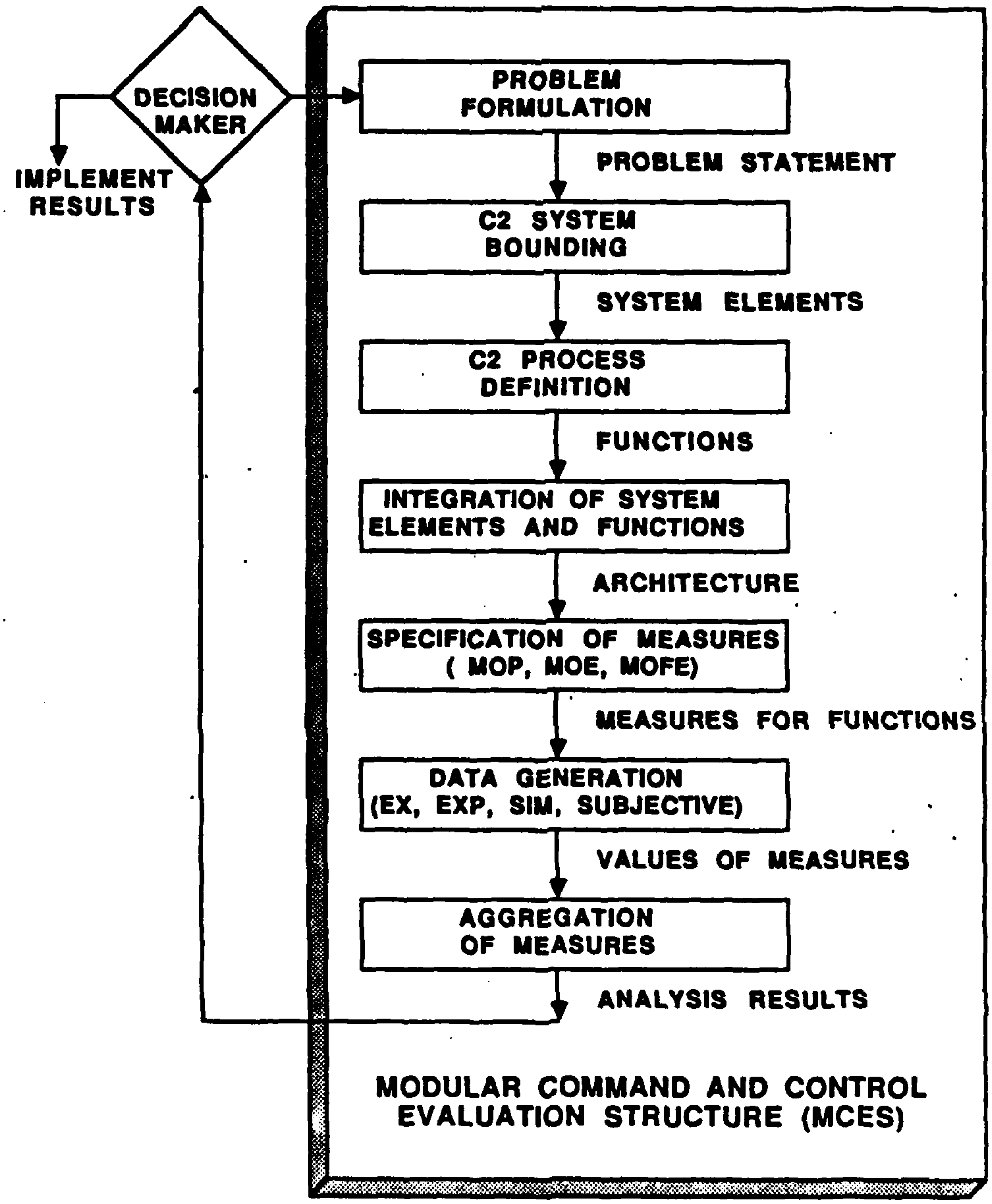


Figure 2.1 Modular Command and Control Structure.

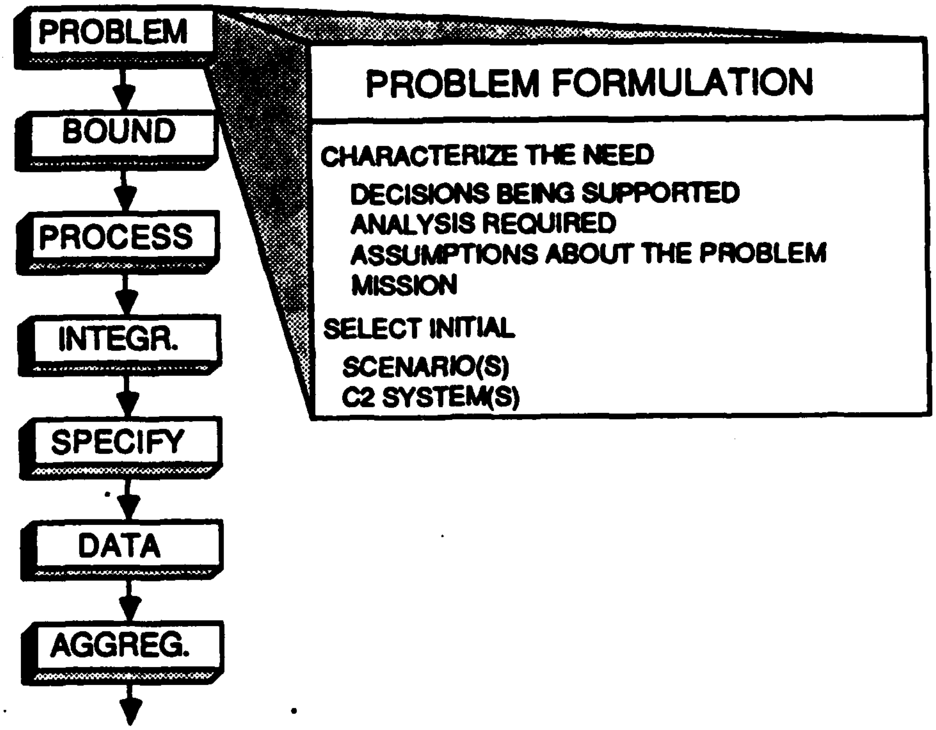


Figure 2.2 Problem Formulation.

used to develop and define a cost-effective system that will satisfy the operational mission. Implications of constraints are determined so that realistic goals for the characteristics can be set.

(b) Acquisition Phase. Accomplish detailed engineering design. The system is built and tested to determine whether or not the system and its subsystems meet specifications. Engineering reviews and test programs are conducted.

(c) Operation Phase. Install the system. Operate and test the system in a realistic operational environment. Assess the capability of the system to meet the effectiveness requirements defined in the concept definition phase.

The identification of the system's life cycle is necessary due to the fact that different points in the life cycle determine which issues are of more concern to the analyst, designer, program manager, and/or user, than others. These issues determine the objectives of the analysis, which in turn directly influences the selection of appropriate measures to be used in evaluating the system and assist the decision maker in reaching a conclusion.

2. Module 2: Bounding the System

The second module will bound the C2 system of interest. It's primary goal is to delineate the difference between the system being studied and its environment. To do this, the analyst must recognize the physical entities, structures and the command and control process completed by the C2 system. Based on the Joint Chiefs of Staff (JCS) definition of a command and control system, JCS Publication 2 states that a C2 system "consists of facilities, equipment, communication, procedures and personnel essential to a commander for planning, directing, and controlling operations of assigned forces pursuant to the mission". [Ref. 6] Conforming to the JCS definition, this three-dimensional definition of a C2 system (entities, structure and processes) are defined as: [Ref. 5: p. 2-3]

(a) Physical Entities: Equipment, (e.g. computer and peripherals, modems, antennas, local area networks), software, people and associated facilities;

(b) Structure: The arrangement and interrelationships of physical entities, standard operating procedures, protocols, concepts of operation, and information patterns such that command relationships and functional representations are established. (Structure frequently reflects doctrine and may be scenario dependent) Such arrangements are often physical and temporal.

(c) Command and Control Process: Refers to the system in its dynamic state. "What is the system doing?" It reflects functions carried out by the C2 system, i.e., sensing, assessing, generating, and selecting alternatives. It is the behavior of the system.

In this module, the analyst must identify the composition of the C2 system being evaluated. For example, physical entities could include the type of computer being used and its physical location, such as the Cheyenne Mountain Complex in Colorado Springs. The structure may represent the organizational structure determined by the C2 system architecture. This may include procedural control in a centralized or decentralized hierarchy.

A graphic representation is often helpful in showing the levels of the C2 system, as defined by the physical entities and structure. This representation is called the "Onion Skin", and can be seen on the lower part of Figure 2.3. It assists in categorizing and identifying the system elements and their level of association with each other. The measures defined below also depend on these relationships.

The final component is process. This is considered to be a dynamic state, whereas entities and structure are more static. The analyst should identify what functions the C2 system should be doing in order to complete the mission of the system. For example, internal C2 processes may include detecting, identifying, classifying or prioritizing enemy actions or weapons.

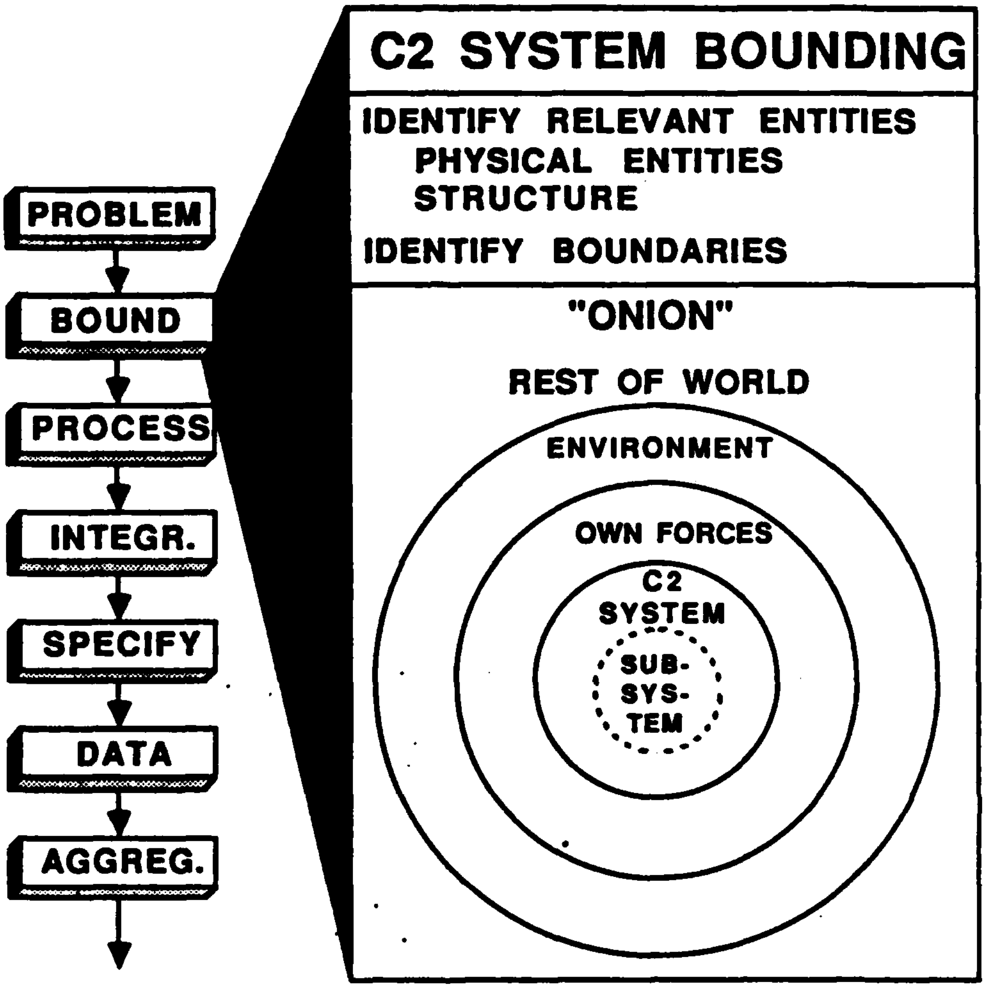


Figure 2.3 Bounding the System.

3. Module 3: C2 Process

In the third module, a conceptual model is used to relate those functions identified in Module 2, to the C2 process of the C2 system being analyzed. Before any further discussions of the "C2 Process" module, the Conceptual C2 Process Model, as seen in Figure 2.4, must be introduced and explained.

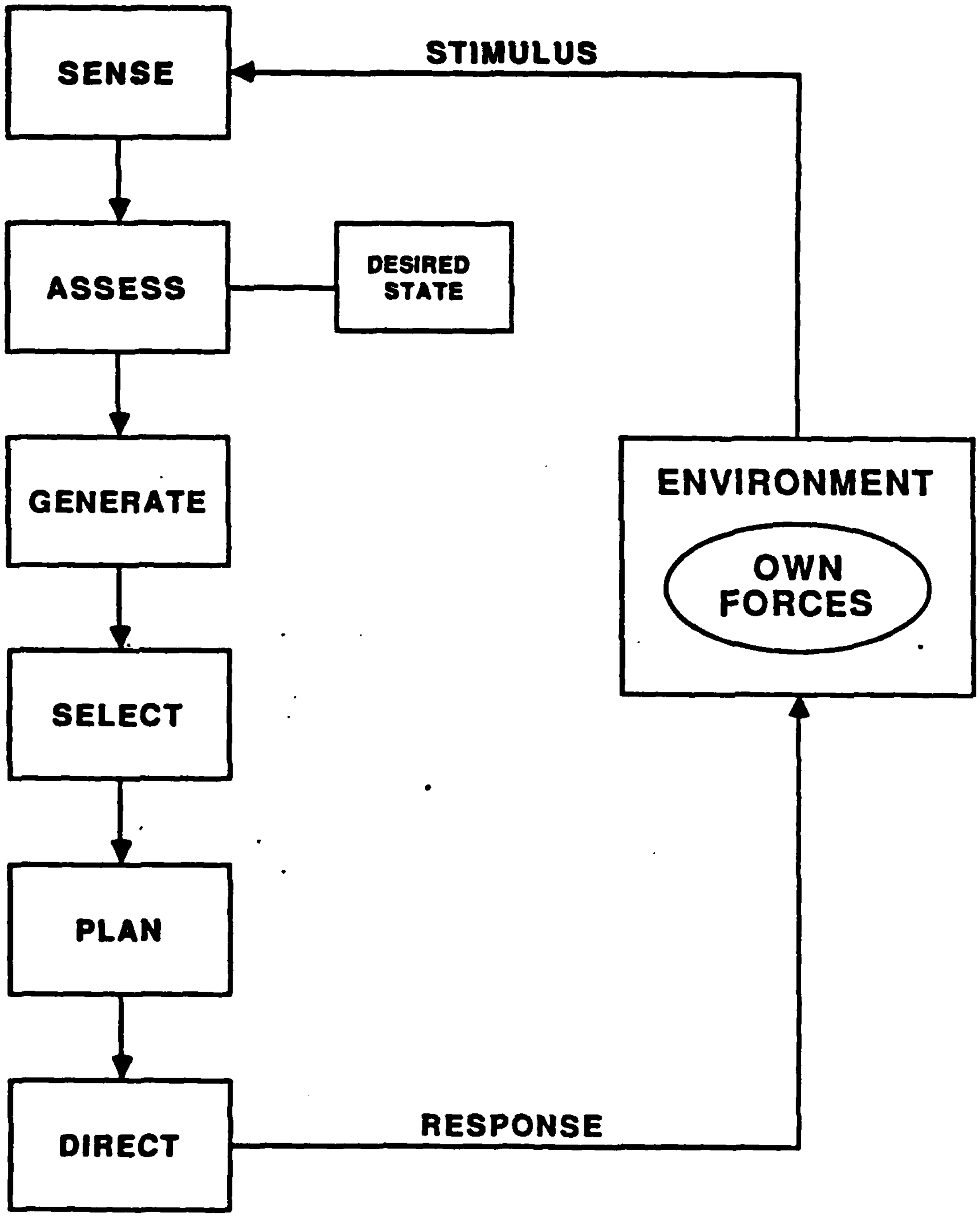


Figure 2.4 Conceptual C2 Process Model.

The Conceptual C2 Process Model was developed to represent the basic constituents of the most simple C2 processes, yet, is able to be applied to most complex C2 systems. The six blocks on the left side of Figure 2.4 are the "functional" blocks of the C2 process model. These functions operate upon and within a defined environment. Actions within the process loop is initiated by a perceived divergence from a desired state and the sensed environmental state. Definitions of the individual functions are presented below [Ref. 5: p. 5-5].

a) Sense. A function which entails gathering the data necessary to describe and forecast the environment, which includes:

   (1) Enemy forces' disposition and actions.

   (2) Friendly forces' disposition and actions.

   (3) Those aspects of the environment that are common to both forces, e.g., weather and terrain.

b) Assess. A function which transforms data from the Sense function into information about intentions and capabilities of enemy forces and about capablities of friendly forces for the purpose of determining if deviation from the Desired State warrants further action. It also integrates data with intelligence for the same purpose.

c) Generate. A function which develops alternative courses of action to bring the perceived environment closer to the desired state.

d) Select. A function which selects a preferred alternative from among the available options. It includes evaluation of each option in terms of the criteria necessary to achieve the Desired State.

e) Plan. A function which develops implementation details necessary to execute the selected course of action.

f) Direct. A function which distributes decisions to the forces charged with the execution of the decision.

A stimulus is an external input to the SENSE block. It is a result of either a natural or human-initiated environmental effect. An action by our own forces as well as by the enemy forces can create an alteration to the overall environment.

The DESIRED STATE block acts as an error function inside the loop. If the actual state differs from the Desired State, the processing activity will continue in the flow pattern seen in the Figure 2.4 . On the other hand, if the Desired State is believed to be reached, processing activity is stopped until the system experiences a stimulus which is sensed and assessed to be an undesirable state.

The basic model has a very simple form, with all of the functions performed sequentially by the conceptual C2 system. A real system, however, may execute the functions in a distributed way, and substantial interactions may exist among sets of C2 systems in the performance of the functions. Further, a given system may, at times,

appear to omit some of the functions or have loops within the model that allow the execution of the basic functions in a different order. Additionally, the conceptual model does not explicitly represent time, even though it is recognized by the MCES analyst that the timing and sequencing of the execution of the functions by a C2 system are major characteristics of the system.

The C2 Process Definition module is an important step for the analyst because a detailed analysis must be made on the C2 system. The analyst must recognize the environmental factors that can threaten the desired state of the system and identify the functions of the C2 process for the stated problem. Then the analyst can map those functions to the generic C2 process loop. As a result, by breaking the C2 process into separate functions, appropriate attributes can be defined and used to measure each function. See Figure 2.5 .

4. **Module 4: Integration of System Elements and Functions**

The fourth module, "Integration of System Elements and Functions," relates the C2 process, physical entities, and structure to form the architecture of the C2 system. See Figure 2.6 . Dr. Sweet defined "architecture" as "an integrated set of systems whose physical entities, structures and functionality are coherently related". The structural framework should be arranged so the system entities have identifiable functions that are performing the previously specified C2 process.

In some studies, identifying the flow of information through the C2 system may help derive a hierarchial relationship between individual C2 functions and to form an architecture. Two techniques have been applied to model information flow through the C2 process model: Data Flow Diagrams (DFDs) and Petri-Nets.

In an air defense study for the Identification, Friendly, Foe, Neutral (IFFN) Joint Test Force (JTF), Major Pat Gandee applied a specific design tool call DATA-FLOW ORIENTED DESIGN, that used the data flow diagrams to model information flow. In his thesis, Major Gandee describes the technique as:

> Data flow oriented design provides a natural methodology for describing a command and control system. It allows us to use data flow diagrams to show the input/output relationships that exist within a C2 system [Ref. 7: p. 48].

The detailed application of this procedure to the air defense C2 process is described in Gandee, 1986.

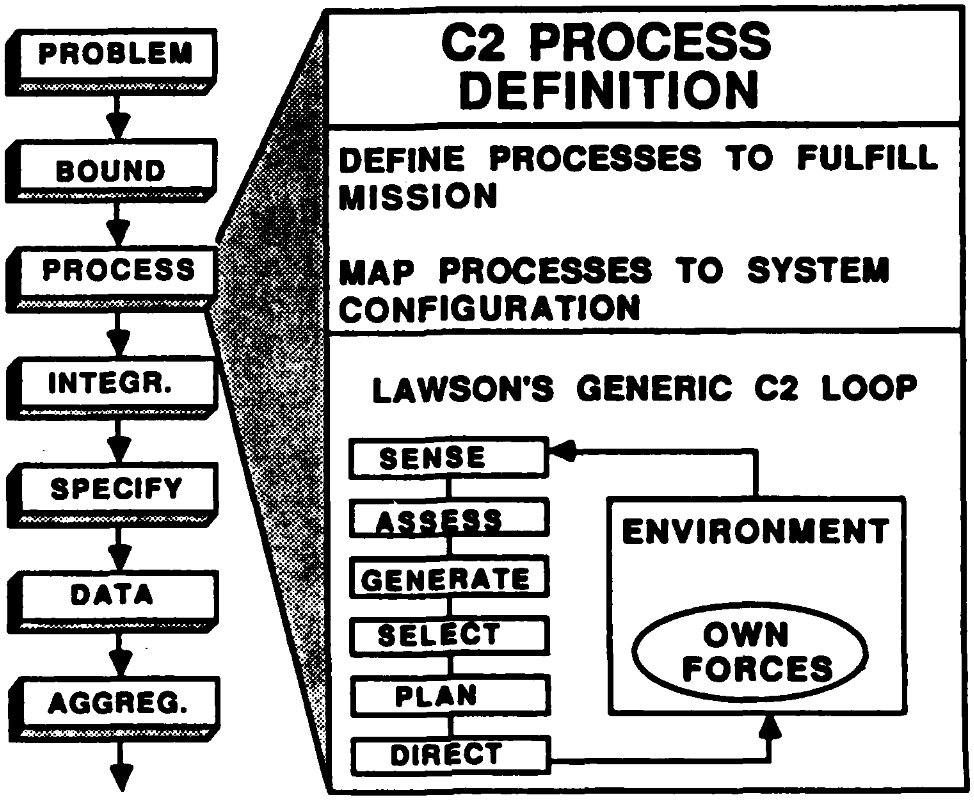


Figure 2.5 C2 Process.

The data flow diagrams can assist in defining the hierarchial "structure" in terms of the information flow between functions within the C2 process. This produces an organizational structure, which could reside in a single node or be distributed between command nodes or between command nodes and weapons. Thereafter, those physical entities (man and/or machine), which perform functions are mapped to the output from the functions.

5. Module 5: Specification of Measures

In the fifth module, guidelines are provided to identify, develop and select measures that will evaluate the behavior/performance of the C2 system in a context

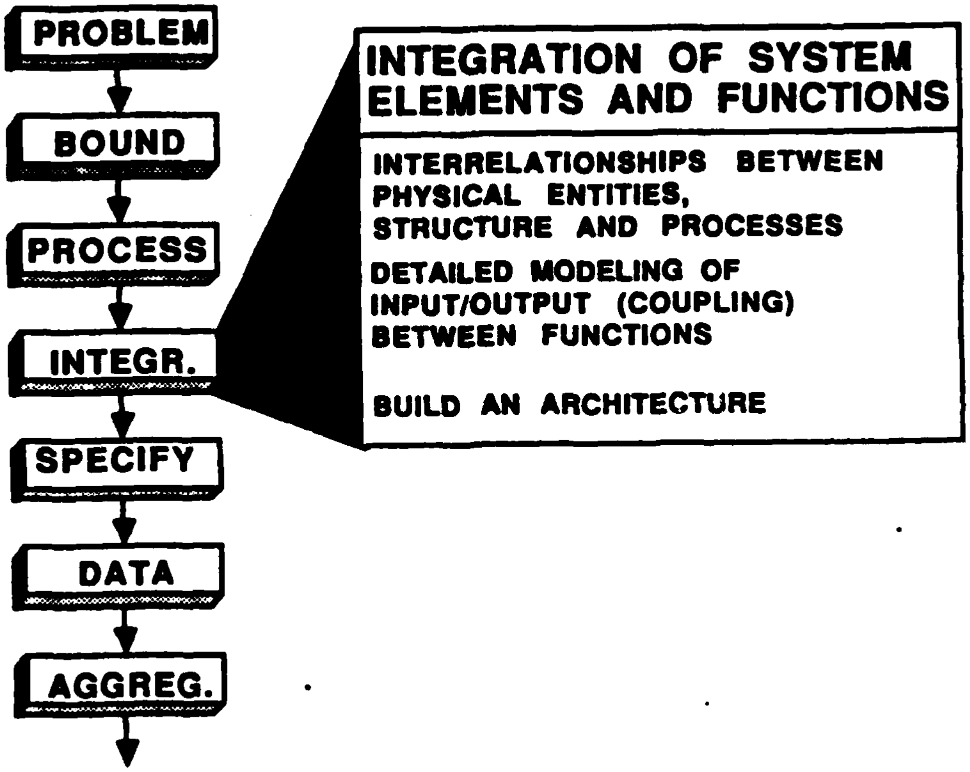


Figure 2.6 Integration of System Elements and Functions.

appropriate to the problem being evaluated. The analytical community has developed a set of terms relating the different types of measures needed for a C2 system. See Table 1 . Although there is debate on how these measures can be stringently defined so as to be comprehensive and distinguishable from one another, the following definitions were presented and used at the C2 Evaluation Workshop [Ref. 5: p. 2-4].

(a) Dimensional Parameters. Properties or characteristics inherent in the physical entities whose values determine system behavior and the structure under question even when at rest (i.e., size, weight, aperture size, capacity, number of pixels, luminosity).

(b) Measure of Performance (MOP). Closely related to inherent parameters (physical and structural) but measure attributes of system behavior (i.e., gain throughput, error rate, signal-to-noise ratio).

(c) Measure of Effectiveness (MOE). Measure of how the C2 system performs its functions within an operational environment (i.e., probablity of detection, reaction time, number of targets nominated, susceptibility of deception).

TABLE I
CRITERIA FOR MEASURES

CHARACTERISTICS	DEFINITION
Mission Oriented	Relates to force/system mission
Discriminatory	Identifies real difference between alternatives
Measurable	Can be computed or estimated
Quantitative	Can be assigened numbers or ranked
Realistic	Relates realistically to the C2 system and associated uncertainties
Objective	Can be defired or derived, independent of subjective opinion. (It is recognized that some measures cannot be be subjectively defined
Appropriate	Relates to acceptable standards and analysis objectives
Sensitive	Reflects changes in system variables
Inclusive	Reflects those standards required by the analysis objectives
Independent	Is mutually exclusive with respect to other measures
Simple	Is easily understood by the user

(d) Measure of Force Effectiveness (MOFE). Measure of how a C2 system and the force, (sensors, weapons, C2 system, and structure) of which it is a part, performs missions (contribution to battle outcome).

From the dynamic standpoint, MOPs are used to measure how well a particular function of the C2 process model is performed; MOEs measure the integration of all C2 functions of the process model in terms of the mission being addressed, and MOFEs relate the C2 system to the force, including weapon capabilities. The same terms can be appropriately applied to C2 system statics as well as to represent integration of statics and dynamics. These measures will provide a standard for comparison as the underlying architecture of the C2 system is reconfigured.

Previous studies have shown that a good starting point for developing measures is to look at the C2 process. Recall the C2 process consists of sense, process, assess, generate, select, plan and direct. These C2 functions could make up the individual MOPs, which, as a set, could contribute to the overall MOE. The C2 process is done to control "our forces" within an environmental context. If there was a way to measure each function's capabilities, then that would represent a set of measures of the control that the force has within the environment. Thus, the C2 system can be measured by the set of MOEs from the entire C2 process. See Figure 2.7.

Relating MOEs to MOFEs and thereby evaluating C2 systems is a complex issue. The precise combination of measures used depends upon the analysis objectives, conceptual model, boundaries and the nature of the analysis. The application determines whether to evaluate the force effectiveness or simply the performance of a given system. The level of the C2 analysis impacts upon the specification of the boundaries for the model.

6. Module 6: Data Generation

The sixth module, as shown in Figure 2.8, recognizes the need to develop a data generator which will provide values for the measures identified in the previous module. Data of this sort has routinely come from analystical tools and available resources to model and/or test system and subsystems capabilities and the overall force effectiveness of the system. Testbeds, simulation models and experiments are an example of possible data generators. Although the data generator may be difficult to conceptualize and build, the numeric values for the measures are the resultant output of this module.

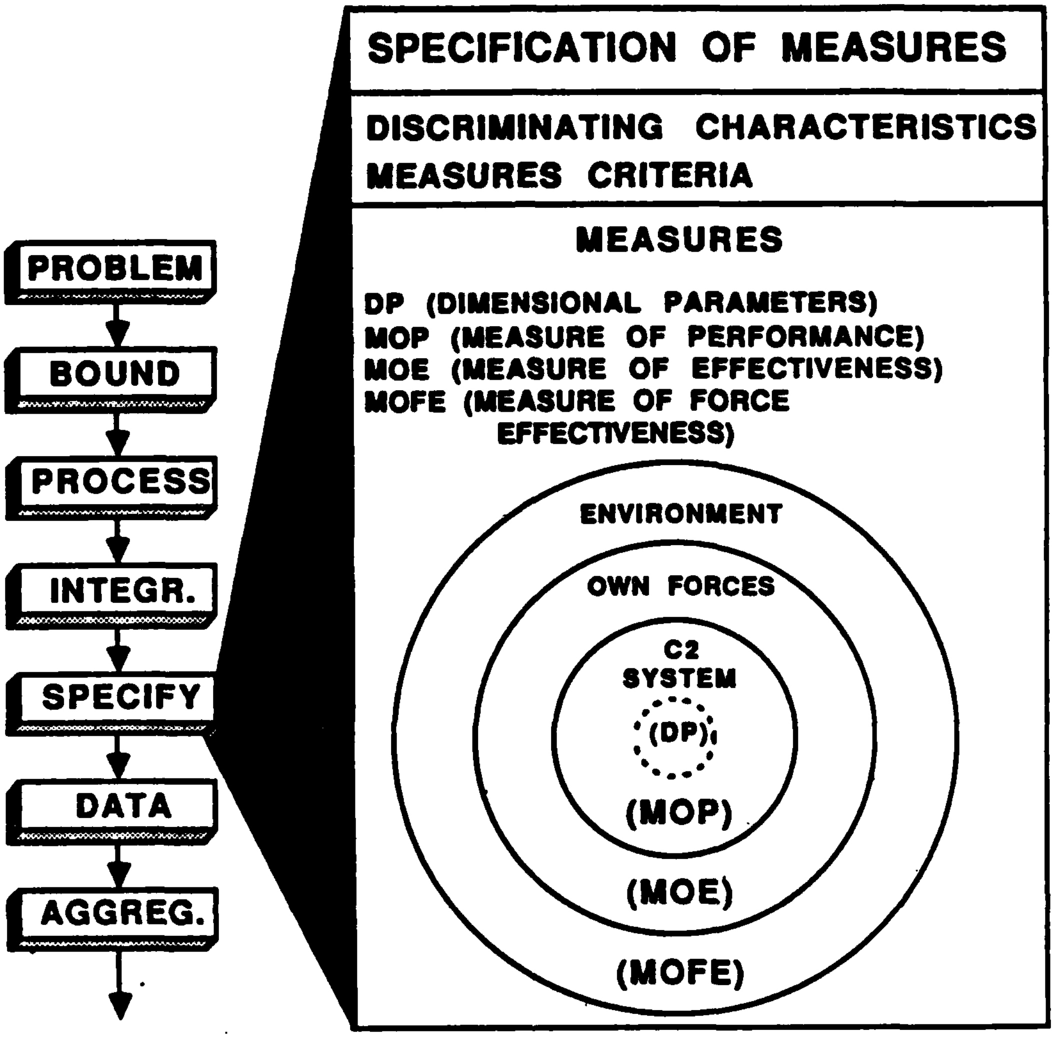


Figure 2.7 Specification of Measures.

7. Module 7: Aggregate the Data

In the seventh module, the analyst must aggregate the measures in such a way that measurement of the C2 system response can be stated as change to the battle outcome. See Figure 2.9 . The implementation of this module provides the analysis results tailored to address the problem initially posed by the decision maker and further qualified in the problem formulation module. Although limited studies have directly addressed this issue, it is clear that the level of aggregation, the life cycle of the military system, and the decisionmaker's organizational responsiblities will interact.

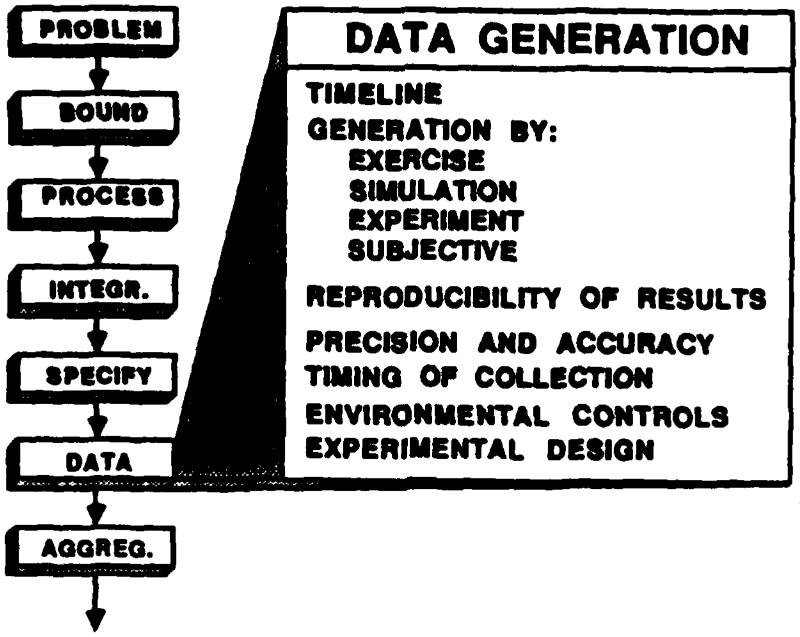


Figure 2.8 Data Generation.

C. CHAPTER SUMMARY

The MCES as developed through meetings, applications, studies and discussions, has provided the community with a theoretical framework for top level problem specification. Testing the MCES with real world military problems has demonstrated it's use as a tool for evaluating the effectiveness of command and control systems. It has also provided: [Ref. 4: p. 116]

(a) A systems theory approach to an integrated view of the C2 system/architecture being evaluated;

(b) A vehicle for the integration of disparate tools;

(c) A standard vocabulary which is beginning to be accepted and used within the analytic community;

(d) The guidance for analytic studies; and

(e) A management support with a decision support system to do architectural comparisons.

Efforts continue to further develop and use the MCES methodology. Dr. Sweet continues to discuss its wide and potential applications with the analytical community while Dr. Sovereign incorporated discussions of the methodology into the curricula of

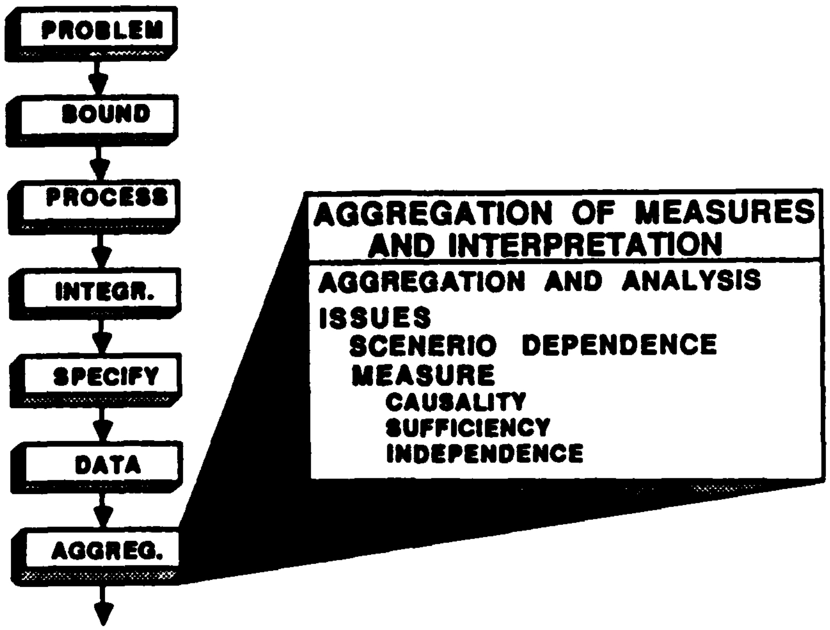


Figure 2.9 Aggregate the Data.

the Joint Command, Control and Communication program at the Naval Postgraduate School, where enrollment includes officers from all branches of the military with a wide variety of military expertise in several different areas.

III. SDI MCES/MOE WORKSHOP

A. OVERVIEW

There has been extensive interest in the continuing evaluation of measurable quantities of C2 systems, as described previously. At the 1986 Evaluation of C2 Systems Workshop, the Joint Strategic Working Group addressed the SDI C2 issue of assigning functions of a physical entity such as a sensor platform so measures (MOPs, MOEs, and MOFEs) could be identified and system effectiveness could be evaluated. The results of the workshop showed promising developments towards identifying appropriate measures for an evaluation plan for competing SDI architectural concepts. Dr. Sweet, under sponsorship of NADC and SDIO, further tested the MCES as a tool for user designated problems in the evaluation of C3 systems by co-chairing an SDI Workshop to extend the work done at the 1986 Evaluation of C2 Systems Workshop. During 9-11 September, 1986, forty-five SDI and MCES evaluation experts attended the SDI MCES/MOE Workshop in Washington, D.C.

B. SDI MCES/MOE WORKSHOP OBJECTIVE

The objective of the SDI MCES/MOE Workshop was: [Ref. 8: p. 2]

> Develop measures appropriate for the evaluation problems within four critical SDI arenas by using the MCES. The Working Groups, the four arenas and their chairmen are listed below:

(a) Working Group 1: The Overall SDI Architecture was chaired by Dr. Thomas P. Rona, Office of Secretary of Defense, Office of Science and Technology.

(b) Working Group 2: Key Architectural Trade-offs was chaired by Dr. Conrad Strack, System Planning Corporation.

(c) Working Group 3: BM/C3 Systems was chaired by Dr. Michael G. Sovereign, Naval Postgraduate School.

(d) Working Group 4: SDI Software was chaired by Dr. Harold Glazer, The Mitre Corporation.

Dr. Sweet co-chaired the workshop with Commander James Offutt, USN, SDIO. Commander Offutt, in his opening briefing at the workshop, described two cases of the BM/C3 evaluation problem. The first case was described as that of the C2 system/architecture overall assessment. This included not only reviewing the performance requirements, but also, measuring the effectiveness of the BM/C3 system.

The second case presented was that of comparing the performance of alternative architectures. As an example, Commander Offutt addressed a five-battle group array and a fifteen battle group array with alternative command and control concepts, i.e., centralized versus a distributed hierachial setup. He went on to say,

> I'm not sure in my own mind what it is we are looking for to measure the effectiveness of this architecture (five-battle group array) versus the other (fifteen battle group array) . . . this measure of effectiveness is a problem.

This tasked the Workshop members to determine the correct measures to evaluate any candidate architectures submitted as an entire SDI system.

C. WORKING GROUP CONCLUSIONS

The intent of this section is to briefly discuss the workings and findings of the two Working Groups dealing with the command and control architectural issues: Working Group 2: Key Architectural Tradeoffs, and Working Group 3: BM/C3 Systems. The results of each group's discussions of the step-by-step flow of the MCES can be reviewed in Dr. Sweet's proceedings of the Workshop, entitled: *The SDI MCES/MOE WORKSHOP.*

The following sections are a combination of the discussions taken place at the Workshop and some drawn conclusions. It should be emphasized that both Working Groups 2 and 3 accepted and extensively used the SDI BM/C3 Working Group for Standards *Functional Decomposition* booklet produced by the SDI Program Office, Hanscom Air Force Base, Massachusetts. This document contains the top level decomposition of SDI BM/C3 functions as determined by the BM/C3 Working Group for Standards. Although both Working Groups felt this document was incomplete, it provided the essential top level functions needed to address any BM/C3 architecture. In addition, both Groups directed their efforts towards the operational SDI architecture. Working Group 2 approached the mission level issues of the architectural components for the SDI system while Working Group 3 addressed and identified system level issues for the BM/C3 architectures.

1. Key Architectural Tradeoffs Working Group

Working Group 2, Key Architectural Trade-offs, first identified three missions of an SDI system: deterrence, protection and escalation control.

Deterrence has been the goal of the entire SDI research work since its announcement by President Reagan. The intent is to show that the United States can make the success of any attack so uncertain that an adversary would not attempt aggression in the first place. This is based on the assumption that no rational aggressor is likely to contemplate nuclear conflict when the ability to penetrate the defensive system and destroy our retaliatory capability remains uncertain.

Working Group 2 identified five ways through which deterrence could be accomplished:

1) Inform friendly and foe populace of the system and our intentions.
2) Integrate the system with other systems and forces during exercises.
3) Demonstrate the system by actually using it.
4) Practice self-defense in tests and exercises.
5) Maintain the system by directing resources towards evolution.

On the other hand, in the case where deterrence may fail, a ballistic missile defense would offer the only hope of protecting U.S. people, forces and C2 networks against a missile attack . Working Group 2 categorized the U.S. assets based on capabilities and placement of the assets. The group first recognized the importance of the National Command Authority and its C3 assets. Without protecting our chief commander and maintaining his ability to control our strategic forces, the initial strike could impede our ability to order a retaliatory strike. Lastly, the group recognized the importance of protecting the human population and the Allied Forces.

Finally, an SDI derived defensive system should be developed with the ability to control escalation. A ballistic missile defense linked to strong air defenses, would tend to stop nuclear war at relatively low levels of violence. Defenses of this type could help conventional forces by protecting vulnerable rear areas. Escalation control was designated in terms of phases and actions, such as attack assessment, stepped response to avoid premature decisions and informing the enemy as to our intent.

Working Group 2 derived measures of force effectiveness (MOFEs) based on these missions. Identifying the MOFEs for the deterrence was based on the visible indicator of the opponents beliefs or reactions. An example of this is the recent summit meeting between the President of the United States, Ronald Reagan, and Soviet leader Michail Gorbachev at Reykjavik, Iceland, in October 1986 (after the SDI MCES/MOE Workshop). In a series of head to head meetings over arms control, the two men came close to agreeing on a plan to eliminate nuclear weapons, however,

President Reagan would not give up the SDI research program for a returned agreement to reduce nuclear arms. When President Reagan refused to end the SDI program, Mr. Gorbachev ended the summit and reported to the media that it was a missed opportunity to reduce nuclear weapons. This reaction revealed the value of the SDI program to the Soviet military program.

Table 2 lists possible deterrent techniques and various "visible indicators" identified by the group members. Deterrent techniques could include such actions as informing other countries and the US populace of the intent behind the SDI system and its capabilities, flexing the system by showing individual subsystem capabilities and performances, and demonstrating the system by actually firing weapons at targets in selective tests and exercises. In addition, advocating the defensive nature of the system as a protection against a nuclear attack and not as an offensive weapon was another deterrent technique.

There are several indicators that would reveal the opposition's belief of our deterrent approach. Such reactions to the techniques could include a commitment of manpower and monetary resources to build a comparative, if not better, system, a change in military doctrine and tactics, an increase in surveillance and intelligence gathering, and the display of negative propaganda towards the use and the reasons for such a system.

TABLE 2

DERIVING MOFES FOR DETERRENCE

Deterrent Techniques	*MOFEs = visible indicators of opponent belief (reaction)*
- Inform	- "Rubles Response"
- Flex system	- Change tactics and doctrine
- Demonstrate	- Reactive threat
- Self-defense	- Surveillance intensity
- Monitor/maintain	- Propaganda

Working Group 2 derived the MOFEs for the "Evolutionary Protection Mission" as being a multiplicative function of the weighted values of the protected system, population or site, the probability of protecting the designated site, the numbers that can be protected and for how long. See Table 3 . However, to further decompose the system, the group found that casual links among system components and its hierarchy provided an elegant strategy for integrating the components, their functions and identifiable measures.

TABLE 3

MOFE FOR PROTECTION

Protect	$MOFE = F(W, P, X, t)$
- Value protected	W = value of Ith type of asset
- How confident	P = probability of protection
- How many	X = number of Ith type of asset
- How long	t = time
- NCA, C3 assets	Value lies in survival of functions such as higher authority, warning assets, emergency action network
- SOF, OMT	Value lies in perceived and actual net retaliatory all-source power
- Allies, population	Value lies in survival of actual entities, not just functions

As mentioned earlier, Working Group 2 accepted the functional decomposition as stated by the BM/C3 Working Group for Standards, but rearranged them to reflect the processes of a C3/BM system. First the system must detect, track and classify missiles through a SURVEILLANCE system. Next it must determine which weapons are capable of intercepting the missile and effectively assign or allocate those weapons capable of engagement. This is BATTLE MANAGEMENT. Last is FIRE/WEAPON CONTROL. The weapon system must be controlled so that individual weapons can acquire, track and engage assigned targets. The Group also

identified subfunctions under these primary functions. Those are designated by the three digit numbers in Table 4 .

TABLE 4

PROCESS AND FUNCTIONS

1.1 SURVEILLANCE

1.1.1 Execute Surveillance Commands
1.1.2 Detection and Aquisition
1.1.3 Track Formation
1.1.4 Obtain Discrimination Data
1.1.5 Obtain Kill Assessment Data
1.1.6 Report Back
1.1.7 Maintain Surveillance Data Base
1.1.8 Maintain Health and Status

2.1 BATTLE MANAGEMENT

2.1.1 Execute BM Commands
2.1.2 Tactical Situation Assessment
2.1.3 Response Plan Selection
2.1.4 Resource Tasking
2.1.5 Kill Assessment
2.1.6 Report Back and Handover
2.1.7 Maintain Battle Management Data Base
2.1.8 Maintain Health and Status

3.1 FIRE/WEAPON CONTROL

3.1.1 Execute Weapon Commands
3.1.2 Target Acquisition
3.1.3 Target Engagement
3.1.4 Report Back
3.1.5 Maintain Fire/Weapon Control Data Base
3.1.6 Maintain Health and Status

The three primary functions lead to the identification of measures to test the performance of the three components that make up an architecture to complete those functions. The components are - the surveillance system(s), the BM/C3 system(s) and the weapon(s). Each of the components were evaluated individually and were assessed by focussing upon their "contributing attributes". Those addressed by the group are listed below.

1) Range and resolution capabilities can be used to measure the effectiveness of sensors, in terms of mission performance.

2) Speed, range, effective capability, environment and countermeasures contribute to the measurement of weapon effectiveness.

3) Connectivity and capacity are seen as effecting a MOE representing the BM/C3 component.

Working Group 2 was instrumental in identifying key issues and possible measures for the evaluation of the SDI system, however, time constraints limited their discussion to selected topics.

2. **BM/C3 Systems Working Group**

Working Group 3 also used the MCES methodology in identifying the measures for evaluating the effectiveness of a BM/C3 architecture to support the deterrence mission. With this recognition, three MOFEs for the BM/C3 system were identified.

(a) The ability to place the right ordnance on the right target at the right time.

(b) Direction of change in the degree of the risk of war.

(c) Extent to which uncertainty among Soviet planners is increased, which is a measure of deterrence independent of actual warfighting.

This Working Group, as did Working Group 2, approached the operational SDI system, therefore, stated that the objective of the BM/C3 system as that of "The ability of placing the right ordinance on the right target at the right time." The group felt this was quantifiable by measuring the number of threat targets engaged within the window of opportunity, however they recognized the need to identify the functions required to accomplish this mission. After hearing Working Group 2's presentation on how they decomposed the top level functions (listed in Table 4) Working Group 3 accepted their list and worked from that. Specifically, Working Group 3 addressed the subfunctions identified under the three primary functions. [Ref. 9: p. 8]

The Working Group had broken the BM/C3 system into four components. Targets, sensors, weapons and communication systems. Each component had several identifiable subfunctions, of which, many were discussed by the Group. One subfunction discussed in detail was matching weapons with targets, or "1.2.4 - Resource Tasking". Parts of the discussions are described below.

To fire accurately, the BM/C3 system must know at each instant of time the location of the weapon platforms and their state of readiness. In addition, the system must know the targets state vector and signature, and the probability of killing the target given its location, trajectory, distance and velocity. This prompted the Working Group to develop lists of target and weapon data needed for weapon target matches. These can be seen in Tables &targ and &weap .

TABLE 5

TARGET PROPERTIES

* History of state vector
* Classification
  - accuracy of signature and vector state
  - time
  - number of objects
* Hardness
* Countermeasures

3. **Target/Weapon Properties**

Both Tables identify the use of "state vectors." I will take some time to explain this term and its usage. State vector has become an accepted term for the SDI community. Although many readers may know the elements that represent the state vector, in the book, *Astrodynamics: Orbit Determination and Space Navigation*, author Samual Herrick discusses the term in the following manner:

> In recent years, and especially in optimization theory and in some of the statistical aspects of correction theory, the "orbit" is often referred to as the "state vector" or "state." These terms came to be applied to the "orbit" partly because of lack of acquaintance with the fact that the six components of position and velocity on any date are often selected for the elements of orbit. [Ref. 10: p. 127]

The elements of an orbit are a selected set of six mutually independent integration constants. It is these six constants that distinguish one orbit from another. These elements are:

(a) a = semi major axis, or mean distance

(b) e = eccentricity

(c) T = time of perifocal passage

TABLE 6
WEAPON PROPERTIES

* Probability of Kill (as a function of)
  - geometry
  - target hardness
  - probability distribution of weapon lethality
* State Vector
  - history
  - quality
* Engagement Envelope (Battle Space)
  - cycle time
  - range
  - fratricide
* Survivability
  - proliferation
  - hardening
  - self-protection

(d) i = inclination

(e) L = longitude of the ascending node

(f) w = argument of the perifocus

Integration and manipulation of these six components through established equations and multiple state vector acquisitions can provide information on the launch point, the distance and time of flight from the launch point to the impact point, and the velocity of the vehicle. Further information on these elements and advanced equations are available in most orbitology books.

Other characteristics of the target properties include the time and number of objects that can be classified, a target's resistance of indention, deformation or destruction by another object (this is often called the "hardness" of the target) and any opposing or retaliatory measures of the targets. Weapon characteristics includes the probability of a particular weapon destroying the target, the area of threat engagement, often called the engagement envelope or battle space, and the survivability of the weapon. The probability of destroying the target would have to include such factors as the location of the weapon versus the target, the hardness of the target and the lethality of the weapon being used. The engagement envelope would take into account the cycle time of the weapon, the range of the weapon and possibility of targeting our own missile. Survivability would have to take into consideration the capability to rapidly replace any damaged or destroyed weapon systems, the hardening of the weapon, and any means of self-protection.

4. **Continuation of Working** Group 3

Knowing that some targets are more important than others, the Working Group recognized the need to prioritize the targets before an assignment of a weapon to a target can be made. To do this, the BM/C3 system must first classify the targets and then prioritize them. Classification must be completed by identifying its launch sites, trajectory, state vector and signature. Once classified, the prioritation of targets can be based on its location, its destructive power, and the value of the asset that it is threatening. Through aggregation, the following measure of effectiveness was identified: Expected percent of threat value destroyed by available weapons.

Three subfunctions were addressed by the Group. These were EXECUTE SURVEILLANCE COMMANDS (1.1.1), DETECTION AND ACQUISITION (2.1.2) and TRACK FORMATION (2.1.3). Under each of these, the Group identified measures of effectiveness for that subfunction and possible measures of performance. These are listed in Table 7 .

Realizing the importance of each component and its associated functions and subfunctions, the Group felt that in order for the BM/C3 system to succeed in accomplishing its primary mission, the architecture had to handle an integration of complete and accurate information flow and highly coordinated data bases while completing those component functions. This is shown graphically in Figure 3.1 . The Working Group discussed several architectural tradeoffs by considering different operational concepts in the context of the BM/C3 structure. These included additional resources such as more sensor information, weapon systems or individual "bullets".

TABLE 7

SUBFUNCTIONS

1.1.1 EXECUTE SURVEILLANCE COMMANDS

Measure: Desired coverage achieved as a function of:

* Probability of command received
* Probability of command understood
* Probability of command acknowledged
* Probability of command executed

1.1.2 DETECTION AND ACQUISITION

Measure: Situation plot versus ground truth

* Percent targets acquired
* Mean time to detect
* Mean time to acquire
* Mean time to resolve clusters

1.1.3 TRACK FORMATION

Measure: Percent objects in track

* Percent objects correctly typed
* Percent duplicate tracks
* Mean tracking error
* Percent false tracks
* Mean time for stereo track

Through the discussions, several general MOPs became evident. One was the time needed to perform a function. Another was how well those functions were performed, for example, the accuracy of classifying targets. And lastly, the completeness of the function, such as the type and number of objects that can be classified simultaneously. In addition to the MOPs relating to the dynamics of the system, or its functions, other generic MOPs were related to the entities themselves, such as survivability and readiness.

D. WORKSHOP SUMMARY

All four Working Groups felt insufficient time was available to address a number of complex evaluation issues for SDI. However, throughout the workshop, it became apparent that development measures, or crude evaluation structures are needed to define the individual problem areas. The Workshop fell short of identifying all those measures, so it was recommended that a SDI MOE panel should be formed. It was

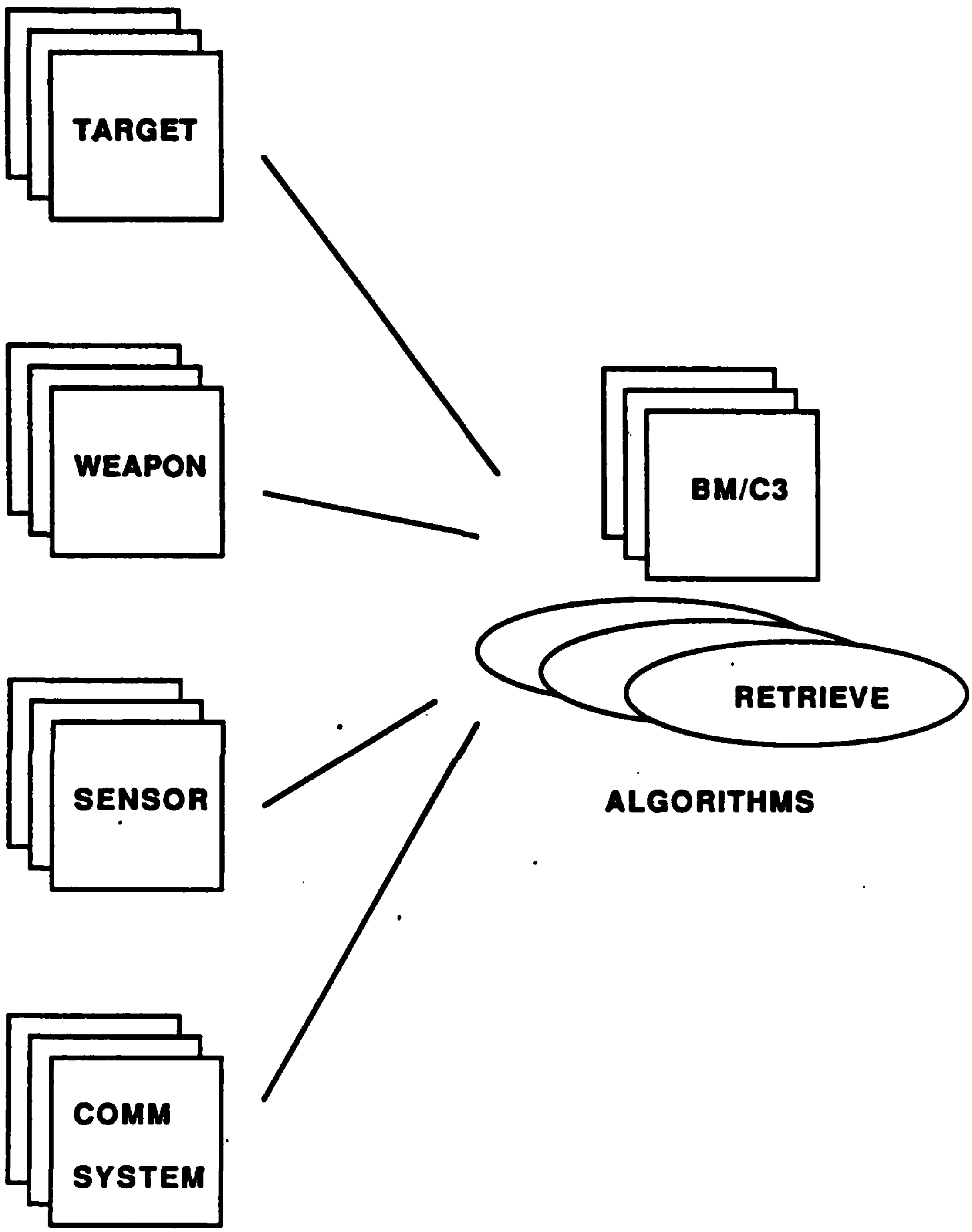


Figure 3.1 System Integration.

further recommended that the panel should be broken into two subsections: an architectural level MOE panel and a system level MOE panel. The architectural panel would continue to identify measures for comparing BM/C3 architecture while the system panel would address the design and architecture of the entire SDI system. These would closely relate to the tasks as those stated for Working Group 2 and 3. These measures, if properly identified and evaluated during simulation models, experiments or exercises, should assist is evaluating the technical feasibility of an SDI system and help determine whether the program should move from the preconcept and definition stage of the life cycle to full scale development.

E. CHAPTER SUMMARY

To date, group and individual efforts are addressing the relevant issues in evaluating the effectiveness of command and control architectures. Some groups are looking at existing C2 systems while others, such as the SDI C2 system, are planning and defining future systems. The MCES is a tool that can be used to address many of these issues. At the start of this Chapter, some of the major events that led to the development and testing of the MCES were described. A description of the MCES was needed so the methodology behind the seven modules was described followed by highlights of the two. Working Groups efforts in use of the MCES to identify and develop command, control and communication measures needed to evaluate the architectures of the SDI system. After participating in Working Group 3, I accepted the challenge of continuing the efforts of the Group but with a smaller, more defined BM/C3 system. This system will be described in the next Chapter.

IV. SDI PROJECT

A. OVERVIEW

After attending the SDI MCES/MOE Workshop, the problem of trying to analyze and evaluate a battle management and command, control and communication (BM/C3) architecture became quite clear. The complexity of the sensors, weapons and battle management systems and the uncertainty of technology and how they should be interconnected not only added to the frustration of trying to build an architecture, but more importantly, complicated the identification of the measures required to evaluate the performance of a system as large as SDI. The BM/C3 system could have hundreds of weapons systems, sensors and surveillance systems, located anywhere from the surface of the earth up to geosynchronous orbit in space. Command centers must operate and control these systems as well as combine and update the data provided by the systems. The coordination requirements could become phenomenal with the communications, data processing and software needed to operate such a system. It is for this reason I chose to evaluate a smaller BM/C3 system, using the "Platform Manager Program" (PMP) concept in addressing command and control issues of an SDI BM/C3 system.

While attending the SDI MCES/MOE Workshop in September 1986, I met Dr. Miriam John, one of the many analysts working on some aspect of the SDI research program. Dr. John and her staff, particularly Dr. Larry Brandt and Dr. Richard Wheeler, all from the Sandia National Laboratory, are researching on-board control of autonomous, or nearly autonomous, weapon and sensor platforms. They called this effort the Platform Manager Project (PMP). The concept behind the PMP is to analyze and evaluate the computational requirements of an on-board "platform manager". The late mid-course discriminator is the first case chosen for this analysis. In this case, through sequential target handling, the platform manager would manager and allocate the platform's sensors so detection and discrimination of incoming warheads in the late mid-course phase would be accomplished. After initial discussions with Dr. John, I decided to use the MCES as a tool to identify measures and address command and control issues of this discrimination platform in a BM/C3 system.

The Eastport Study Group initially recommended that the coordination required for each phase of the defense should use a decentralized and loosely coordinated approach to battle management. This was further briefed by Lt Gen. Abrahamson as an acceptable approach to the hierarchal structure for the SDI system. This directly related to the basic principle of centralized control and decentralized execution. The SDI command and control system would have a central control node with a single strategic defense commander for coordinating efforts of the forces' command and have subordinate nodes for execution of operations. Lower echelon commanders would have wider use of judgement in employing the capabilities and characteristics of the ballistic missile system. The Sandia PMP is consistent with the Eastport Study Group's recommendation and Lt Gen. Abrahamson's approach to decentralize the BM/C3 architecture. The initial PMP technology has limited range so a single discriminator platform could protect a limited area (e.g. a group of silos or a localized command center). The activities of the platform would be coordinated to a localized command center as a lower echelon command node. This approach makes the discriminator platform and a command center a viable single-layer BM/C3 system that could be a deployable system in any proposed multi-layer BM/C3 system.

The initial concepts have the discriminator platform operating in the late mid-course/terminal phase of the missiles trajectory. This, too, is consistent with Lt Gen Abrahamson's comments at the AIAA conference of a "tier defense"--the first tier being the boost/post boost phase and the second tier being the mid-course phase with the possibility of the terminal phase as the third tier.

B. SANDIA PMP PROJECT DESCRIPTION

The BM/C3 system incorporating a platform manager on a discriminator platform is only a small segment of the entire BM/C3 architecture, but it, too, must address similar command and control issues as those discussed by the BM/C3 Working Group of the SDI MCES/MOE Workshop. Before continuing, an explanation of the initial case study for the PMP due.

1. Platform Manager Program Concept

The platform will have sensors that will track reentry vehicles, decoys, chaff and other debris and provide data that will help discriminate targets that are reentry vehicles from others that are considered less significant. Hence, it is referred to as a dedicated discrimination platform. The Platform Manager Project (PMP) uses the

dedicated discrimination platform in a "pop-up" basing mode. In this scheme, the platforms are kept on the surface of the earth until needed and then "popped-up" into space with a predetermined trajectory. The intent is to have the platform follow a trajectory such that the reentry vehicles pass through the platform's sensing field, commonly referred to as it's "field of view". If the platform sensors are able to acquire the targets and discriminate the threatening targets from decoys or other debris, then the target's tracking information and state vector can be relayed to either a weapon system or command center, or both, so action can be taken. Figure 4.1 shows this scenario.

The basing mode and the operational concept behind the platform dramatically increase the survivability of the system during a conflict. These surface-based systems would be placed in friendly territory where physical protection is maximum. It attempts to overcome the enormous vulnerability problem with the space based systems. In space, systems can be tracked and monitored by the Soviets at all times and are vulnerable to the Soviet anti-satellite system or their space mine destructive capabilities. In addition to the physical protection, the platform's trajectories will be unpredictable by the enemy due to the number of possible launch trajectories. This would prevent, or drastically hinder, the Soviet's ability to launch the missiles with a flight path that would not enter into the platform's detection range.

Due to its basing mode, the weight of the platform plays an important role in its launching capabilities. The uncertainty of the weight has a direct impact on the size of the booster required for launching the platform into high altitude, say, several kilometers up from the surface of the earth. Taken into consideration the latest technology of the the sensor systems and booster capabilities, initial studies have shown that the weight of the platform shouldn't pose any problems with the operation of this system.

2. Detail System Description

Before launching, an early warning surveillance system must detect the enemy's attack and determine probable missile trajectories. The pop-up platform requires prior notification of an oncoming threat so it can be boosted out of the atmosphere to engage the oncoming threat. (The particular discrimination technology employed requires a high altitude line of sight between the platform and the target). There are several existing and planned surveillance systems to do this. The first system that should detect a ballistic attack is our early warning satellite system. Infrared

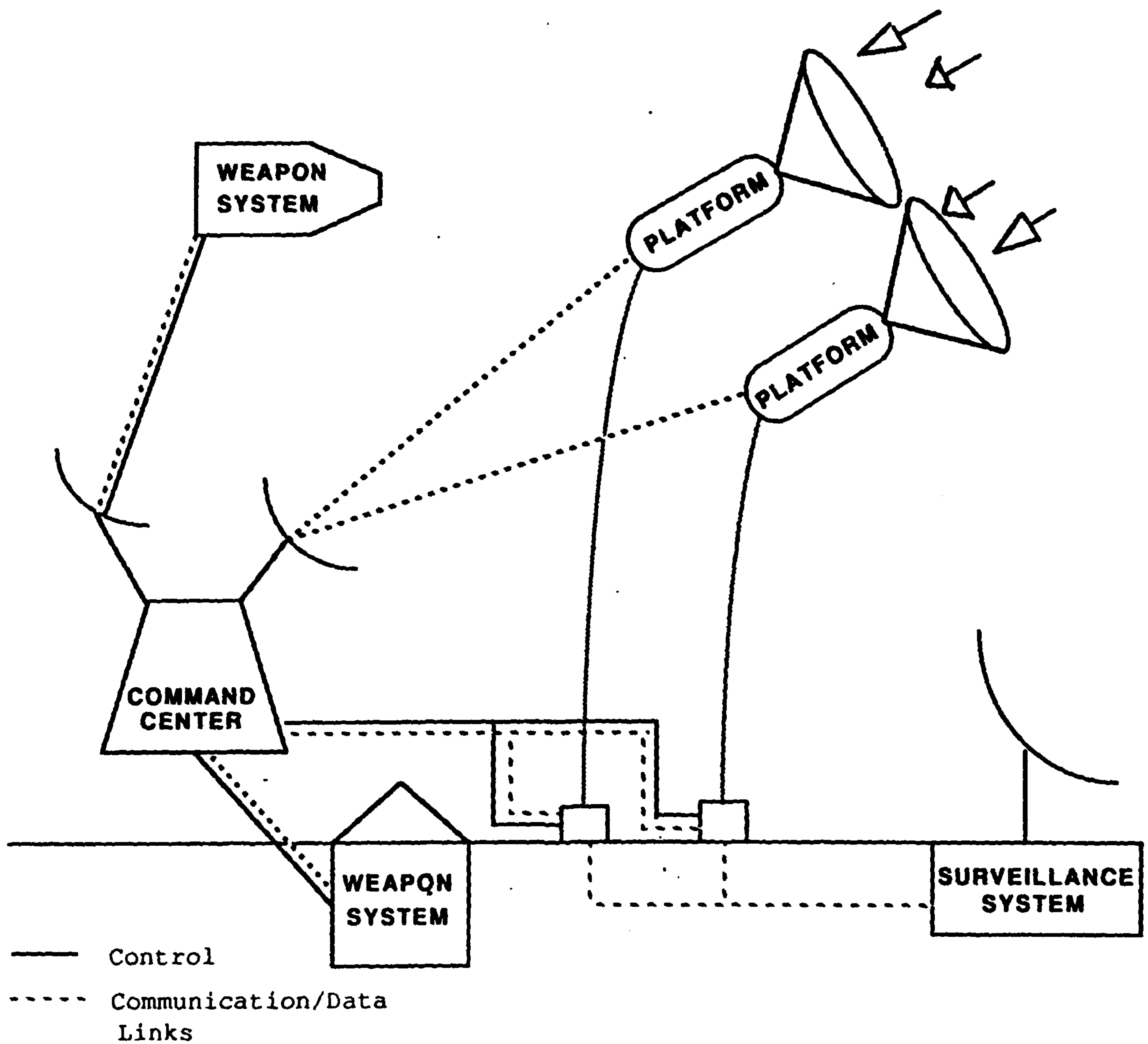


Figure 4.1 An SDI C2 System with the PMP concept.

sensors should detect the booster's flame and provide launch point and launch count. A second system, the Ballistic Missile Early Warning System (BMEWS) can also track the missiles. This system is designed not only to confirm an attack is underway, but also to provide impact predictions. For warning of SLBM attacks, the early warning satellite system is complimented by PAVE PAWS phased-array radar systems. These are strategically located at three different sites in the U.S. so their radar sweeps cover the entire continent.

In addition to these systems, future warning systems are being researched and developed. One such system is the Boost Surveillance and Tracking System (BSTS). This system is being designed for the boost phase. It will provide rapid and reliable warning of attack as soon as a launch occurs. For accurate and efficient tracking in the boost/post-boost phases, the Space Surveillance and Tracking System (SSTS) concept is being considered. The SSTS would provide a nearly real-time, fully responsive space-based system for surveillance and tracking, and timely satellite attack warning and verification. also provide the tracking data for hand-off to the late mid-course and terminal phase sensor systems.

If the warning and surveillance systems reflect that the missiles have a trajectory such that the reentry vehicles are within the platform's sensing field, then a command must be issued to launch the discrimination platform. Once given, the platform will "pop-up" off the surface of the earth via a planned trajectory. The platform will have an attitude control system so that the on-board sensors can be pointed, but the area coverage of the sensor systems will be limited. Once the launching boosters burn out, the platform will have a translational motion as that of a free falling body. Therefore, not only does the platform have a limited coverage, it has a limited life-time, too.

Once in flight, several sensing subsystems must coordinate activities and information if the platform is to succeed in its primary mission of tracking missiles and discriminating between real warheads and decoys. The first sensor would be an acquisition sensor. A most likely candidate for this would be a passive infrared sensor, called a "staring" sensor. It will scan its field of view for threatening warheads. The main objective is to determine the locations of the targets from the platform and the number of targets within "prepartitioned areas" representing its field of view. These prepartitioned areas may be thought of as a two-dimensional graph, as seen in Figure 4.2 . As the staring sensor detects the reentry vehicles, the reentry vehicle will

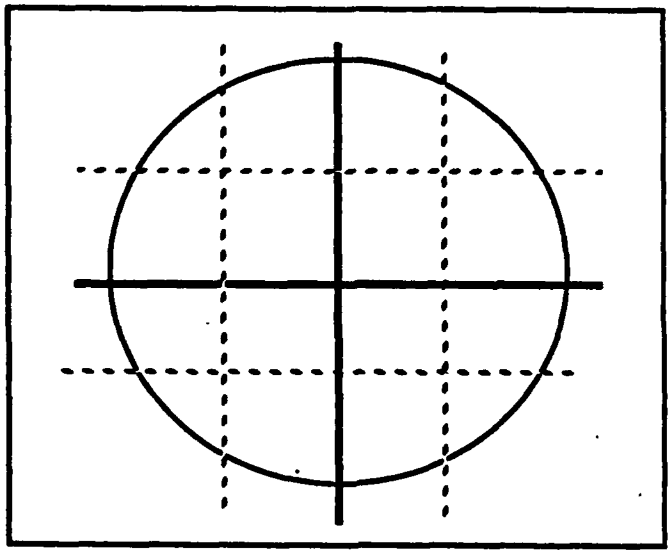


Figure 4.2 Sensor Prepartitioned Areas Concept.

correspond to an area on the graph. The size of the area is still being researched, however, this information will identify the area or areas with the highest concentration of detected targets. Range information and detailed resolution are not within the limited capabilities of the staring system due to the limited information that can be extracted from an IR sensing system. The information about the areas of higher concentration rates will be used by the "platform manager" to assign a second sensor of the platform to further assess the targets.

The second major sensor onboard the platform is the tracking sensor. The information from the staring sensor must be processed by the platform manager such that the tracking sensor will continue to scan the areas identified by the acquisition sensor. Because of the accuracy needed in generation of track files, this second sensor is likely to be an active sensor, such as a laser radar, commonly called a LADAR. This sensor generates the fine tracking information needed to point an onboard directed energy beam at the target for discrimination.

After track information of the targets becomes available, the platform manager processes the information to control the platform resources. The primary resources to be allocated is the charged particle beam which is sequentially aimed at the incoming targets. It is the interaction of this beam with the targets that permits the discrimination of reentry vehicles from decoys. This is done by probing the targets with a directed energy beam such that radiation scatters or bounces off the nuclear warheads with identifying signatures. The signatures must be received by the platform and processed by the platform manager for complete target discrimination.

The LADAR high-resolution capabilities and the platform manager processing capabilities will enable the system to maintain and update the state vectors, status and locations of all threatening warheads and probable impact points. This highly defined and accurate tracking data must be sent to the command center to determine which weapon systems are capable of intercepting the threatening warheads and which targets should be intercepted first.

The command center is considered the battle manager of this system. Once the information is received by the command center, threat assessment must take place. The data from the estimated impact points can be used to evaluate the threats posed by the reentry vehicles. Then, through effective manipulation of information about the defensive battle, that information can be used to priorize the warheads and allocate individual targets or groups of targets to a weapon or weapon platform according to weapons system location and capability of intercepting the threatening warheads. The basic idea is to optimize weapons assignment based on the weapons' and missiles' positions and capabilities to avoid expending multiple shots at one missile while others are ignored.

In addition to the responsibilities such as approving weapon assignments and authorizing weapon firings, the command center may also be involved in the exchange of a large volume of information about the location of missiles as viewed from each sensing platform. The measurements made by the sensors can be combined or "fused" in the battle management system in order to improve the completeness and accuracy of tracking the RVs and their battle assessment. Major Pat Gandee, in his thesis on air defense, described this as a critical function within a geographically distributed C2 system. He termed this as the "crosstell process" and defined it as:

> That process which provides for sharing of information throughout the C2 system to support decision making. The process can also support implementation of those decisions. [Ref. 7: p. 38]

This shared information will provide the area commander a complete picture of the current situation. I would like to emphasize that this C2 system would be geographically bounded and would not be responsible for the entire spectrum of weapons, sensors and communication systems of the ballistic missile defense.

Higher level coordination is not seen in Figure 4.1, however, it must exist to control the entire SDI system. A few passing comments are in order to describe how this coordination might take place.

For threat assessment a report would be furnished to higher authorities in the hierarchy detailing the status of the command center and its systems and the local situation. The higher-level battle manager would combine the threat assessments from the local command centers and any other national collection sensors to present a condensed threat assessment to the national command authority. This level of coordination will involve the collection and processing of massive information from each of the command centers to possibly a central point, or command post. It will provide a means of keeping the higher levels informed and up to date on the battle situation as seen from the command centers and sensors. These layers of individual C2 systems make up the entire overall SDI C2 system. As one can see, this increases the complexity of the BM/C3 system needed to support and control the entire SDI system.

3. BM/C3 System Functions

The command and control system, of which the platform discriminator is a part, is to gather information about the incoming reentry vehicles, analyze the potential threat each reentry vehicle imposes upon the U.S. and direct forces to negate the threat. In reviewing this C2 system several functions of the system became evident. These are:

(a) Warning/Alert
(b) Acquire
(c) Track
(d) Discrimination/Classifying
(e) Threat Assessment
(f) Weapon Assignment
(g) Weapon Allocation
(h) Fire/Weapon Control

Several of the functions correspond to those definitions stated by the SDIO BM/C3 Working Group for Standards in the document *Functional Decomposition.*

Others have been discussed, developed and defined in prior meetings, symposia and research documents. The definitions I will be using are a combination of those definitions defined by the *Function Decomposition* document and those defined in prior meetings and reports. They are defined as:

a. Warning/Alert Function

This is the function in which the results of early warning systems produces electronic or visual evidence that the enemy has launched an attack; define launch location, order of battle, and intensity as a function of time for initiation of the battle; provide track data for hand-off to other vehicle tracking systems.

b. Acquire

This is the function in which searches are carried out by passive or active sensors until the presence of objects in the area under surveillance is established. [Ref. 7: p. 34]

c. Track

This function establishes and maintains continuous contact with detected objects; establishes location, state vector and trajectory of the detected object; assigns trajectory identification symbol for common reference. [Ref. 7: p. 34]

d. Discriminate/Classify

This function obtains data on the trajectory histories, passive and active signatures and interactive response of tracked objects; target classification must occur. [Ref. 9: p. 34]

e. Threat Assessment

This function determines the impact points and evaluates the threats posed by detected targets; target prioritation takes place in accordance with a preplanned priority strategy. [Ref. 9: p. 27]

f. Weapon Assignment

This function considers the best option of weapon system (space or ground-based) given resource availability, capability and priority; pairs weapon system to prioritized targets; response plan is implemented in accordance with established priorities and specified strategy. [Ref. 9: p. 23]

g. Weapon Allocation

This function considers options (within the selected weapon system) and pairs specified weapons to target after considering limited resource availability. [Ref. 7: p. 34]

h. Fire/Weapon Control

This function provides target data to weapon systems and directs the firing and launching of weapons. [Ref. 9: p. 30]

In effect, the above definitions correspond to the C2 process definition. It reflects what the system is doing and the functions carried out by the C2 system--sensing, assessing, generating, selecting alternatives, planning and directing. Identifying and defining these functions early on will become useful when applying the MCES to the Platform Manager Program C2 system. This will be discussed in more detail in Chapter Five.

C. CHAPTER SUMMARY

In this chapter, I have introduced the problem of addressing the BM/C3 system, as a whole, for a system the size envisioned for the SDI project. For this reason, I found a smaller BM/C3 system that could be applied to the MCES to address similar C2 issues as that of the larger SDI BM/C3 system. This smaller BM/C3 system would operate in the same environment under the similar conditions as the larger system, but at a lower level. I described the "pop-up" platform in some detail to explain its operations and the components it must interact with as a BM/C3 system. The final section of this chapter identified several functions a BM/C3 system must complete to command and control resources in the pursuit of a mission. Since Chapter 2 explained the MCES methodology and this chapter provides and overview of the PMP concept, I'm now ready to apply the MCES methodology to the PMP C2 system to identify measures to evaluate the performance of the system.

V. THE BM/C3 PROBLEM

A. THE MISSION

Deterring a Soviet attack against U.S. forces or cities is the primary mission of the Strategic Defense Initiative (SDI). If that fails, the SDI system must protect the United States from a nuclear attack. The elements within this mission include the enemy's ballistic missile threat, its goals and a ballistic missile defense (BDM) that must deny the enemy its goals. Within minutes of a Soviet ballistic missile launch, the Soviets could destroy various elements within our force structure. Targets include missile silos, cities, ground based assets such as command, communication, and surveillance centers, or the SDI weapon and sensor systems themselves.

The battle management and the command and control system of the SDI system must help decision makers identify a ballistic missile attack, determine the threat they pose to the U.S. and direct sufficient weapons to negate the attack in a near real-time environment. Two kinds of attack are of concern to U.S. planners. The first is an unexpected attack against forces on day-to-day status, rather than a generated alert status. This attack could include an accidental outbreak of war, although a deliberated attack is thought to be more likely. The second kind of attack is the preemptive strike, made during a crisis in which the Soviets fear that war is imminent and that striking us first is the best course of action to reduce damage to themselves. The Soviets may attempt to disguise their attack by launching debris or decoys or they may try to saturate the BMD beyond its capacity, or a combination of both. Therefore, the SDI system and its associated BM/C3 architecture must be able to handle any influx of enemy missiles at any time such that forces can be directed to counter it.

Several C2 issues must be addressed when trying to determine the BM/C3 architecture that will provide the battle manager with the most timely, accurate and complete information needed for him to effectively use his forces. The remainder of this chapter will address some of these BM/C3 issues by applying the MCES methodology to a small BM/C3 system, comprising of a "pop-up" platform as the sensor system, a weapon system and a command center. This system will be comparatively much smaller than the BM/C3 system required to command and control the SDI system in its entirety, however, many of the issues that will be discussed on

this system are the same as those that must be addressed in analyzing any SDI BM/C3 architecture. The seven-module MCES methodology will be used to analyze the functions and processes required to complete the mission of the BM/C3 system and identify possible measures that can be used to evaluate the BM/C3 architecture. By identifying the system functions, the C2 process and possible measures, simulation models and experiments can be developed to evaluate the effectiveness as a command and control system. These will be discussed only at the Sandia Platform Manager Program (PMP) concept level.

B. MCES APPLICATION

1. Problem Statement

Based on the need to evaluate SDI C2 systems, a general problem statement can be formulated:

> How autonomous can the command and control system be if many of the decision making capabilities are shifted to the computational capabilities of the platform manager (onboard the discriminator platform) and the command center.

The PMP system is a single layer portion of a multi-layer BM/C3 system. The approach envisioned by a multi-layer defense is that each layer will be capable of performing independently the basic functions described in Chapter 4.3. Recall, that the second-tier defense must protect the U.S. against offensive weapons which have not been killed in the proceeding phases of the defense. The major requirements behind this type of architecture is it must not only survive, it must be effective in defending the predetermined high-priority sites or areas.

Applying the MCES to the Sandia National Laboratory's PMP concept will not only identify which systems are performing which functions, but it will provide guidance on identifying and selecting measures to evaluate the performance of the system. If the performance of the system can be quantified and a standard can be established to assess that performance, then the effectiveness of the system can be evaluated.

If all alternative C2 systems would have similar measures, comparisons of those systems might determine which system is better for a particular scenario or mission. This BM/C3 system is being designed to operate autonomously while protecting a small area such as a group of ICBM missile launching sites. To simplify

the analysis, it will consist of only one sensor system and one weapon system under the responsibility of one commander in a command center.

2. Bounding the System

The primary objective of "bounding the system" is to delineate the difference between the system being studied and its environment. As described in Chapter 2, the onion-skin graphical representation is useful in showing the levels of the C2 systems. Recall, JCS defines a C2 system as "consisting of facilities, equipment, communications, procedures and personnel essential to a commander for planning, directing and controlling operations of assigned forces pursuant to the mission assigned."

a. Onion-skin Representation

The C2 system with the pop-up platform, as seen in Chapter 4 Figure 4.1, is only a part of the entire C2 system needed to manage and operate the large number of weapons and sensors comprising the ballistic missile defense. Figure 5.1 shows how this BM/C3 system fits into the overall military command and control structure. The system being analyzed is designed to intercept targets in the late mid-course phase of the missile's trajectory. Other BM/C3 systems must be developed to handle the targets in the boost, post-boost or terminal phases of the ballistic missile trajectory.

A separate command and control structure would have to be identified for the ballistic missile defense. This could be called the Strategic Defense Command System (SDCS). It would provide the means through which the SDCS commander sends and receives information and exercises command of the space, air and ground-based systems by transmitting his decisions to lower-echelon SDI C2 systems. Although the overall BM/C3 architecture may be unique in its particular mission, the lower level BM/C3 systems, such as the PMP system, which is designed for mid-course interception, must all be implemented to assist the SDCS commander in planning, directing and coordinating his forces in pursuit of the mission--protect vital assets of the United States. This is turn must be incorporated into the National Military Command Structure (NMCS).

The National Military Command System (NMCS) is the primary means by which the National Command Authority (President and Secretary of Defense) commands and controls the forces of the United States. The Department of Defense is the military organization that provides the forces to protect and defend the interests of the country. The purpose of the DOD is to maintain and employ the military

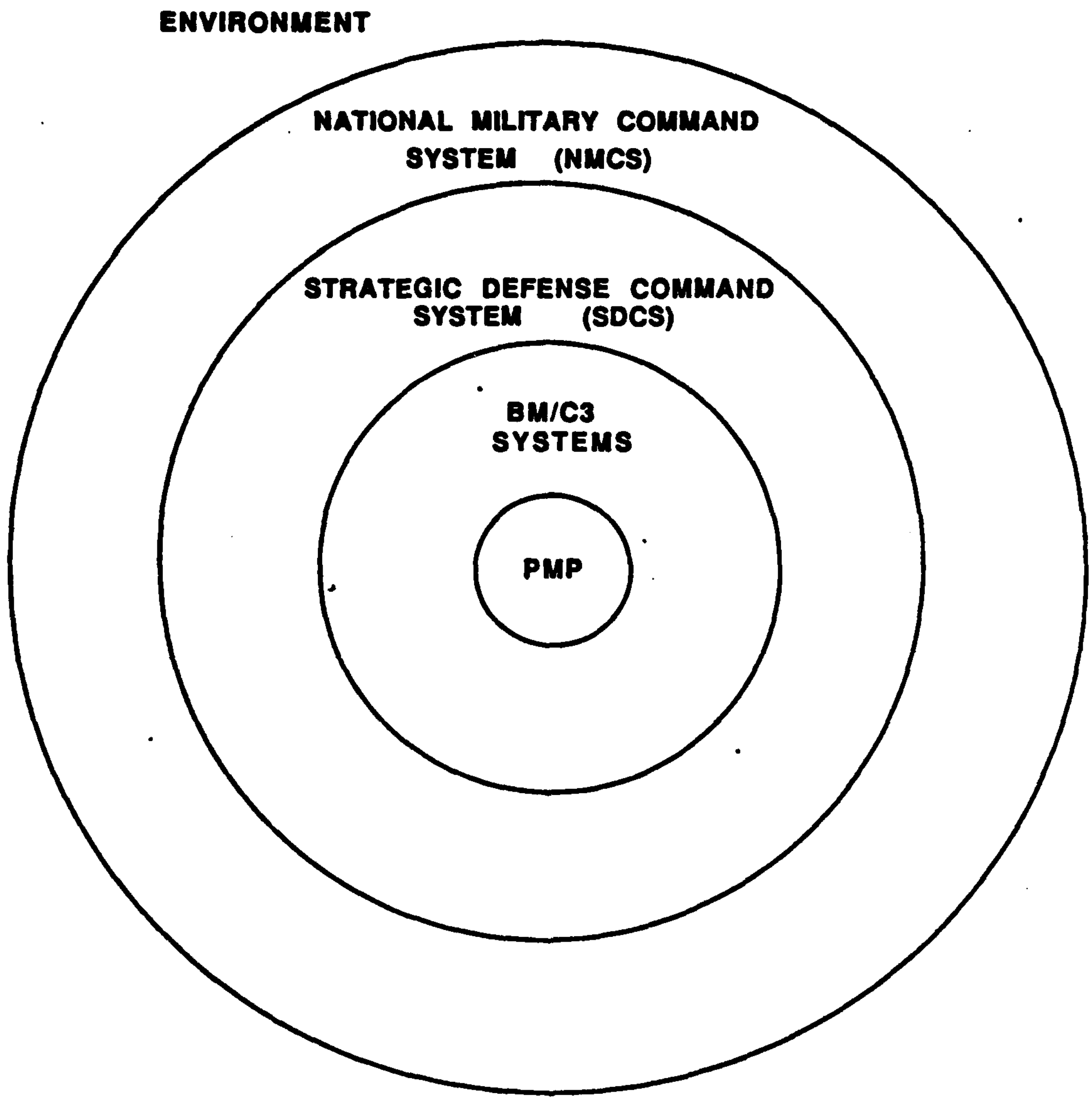


Figure 5.1 Onion Skin Representation.

instrument of the national power under the direction of the President, as Commander in Chief, and the Secretary of Defense and in response to the legislative mandates of the Congress. This is done through the World-Wide Military Command and Control System - WWMCCS.

The WWMCCS is an arrangement of personnel, equipment (including automated data processing equipment and software), communications, facilities and procedures employed in planning, directing, coordinating and controlling the operational activities of U.S. military forces. It is intended to provide the NCA a capability to: [Ref. 11: p. 58]

(a) receive warning and intelligence information
(b) apply the resources of the military departments
(c) assign military missions
(d) provide direction to the Unified and Specified Commands

In other words, WWMCCS provides the NCA a means to perceive the national security environment and control the military resources of the nation.

As the primary component of the NMCS, the WWMCCS is composed of command and control systems of the Unified and Specified Commands, Headquarters of Service Component Commands, our Triad forces, North American Defense, (NORAD) and other DOD agencies. If the Strategic Defense Command System is developed, it, too, must be integrated into the NMCS. Although these individual C2 systems are configured and operated generally to meet the requirements of the command agency or department being served, the first priority of each of these systems is to support the NMCS.

Encasing our government and military system is the outside world. This includes not only allied and neutral countries, but also possible hostile countries with nuclear and conventional destruction capabilities. If a ballistic missile defense is to be employed, it must be incorporated into our national political and military goals and in the context of world-wide stability. It must not undermine or threaten friendly countries nor hamper future political and military relations with them.

In short, the C2 systems of the DOD are the means by which our military commanders, under the direction of the President, employ the military strength of our nation. Any ballistic missile defense and its command and control system must be integrated into the NMCS and must be a military instrument of national power under the direction of the NCA through the NMCS. The BM/C3 system being analyzed here

must be a part of the entire battle management and command, control and communication architecture for the SDI system.

b. Physical Entities

In bounding the system, I've constructed a simplified version of a command and control system in using the PMP concept. The C2 system being addressed will have only one surveillance, one sensor, one weapon system and one command center. See Figure 5.2 . All the functions that must be accomplished to complete its mission must be completed by one of these four systems. Although this severely restricts the number of components interacting within the system, system integrity is maintained and the complexity of command and control issues remain easily identifiable.

Physical entities of the system include not only the equipment and facilities but also the software and the people. The equipment would include the surveillance system, the pop-up platform and its launching system, the weapon system, the built in computer software and processors needed by each of the systems in order to operate, and the communication equipment needed to interconnect the physical entities. The command center would be the operational control facility of this system performing the battle management functions while the operators would be the personnel maintaining its readiness. The commander will be the ultimate decision-maker.

Software would include such things as command processing algorithms, data management, vast amounts of storage and memory capabilities, databases and input/output formatting procedures. Algorithms would be built to perform such functions as situation assessment, damage assessment, defensive firing strategies, networking, and many others. If incorporated, the algorithms must deal with complex rules of engagement and rapidly changing environmental conditions such that the mission can be completed by the system. Due to the limited time any BM/C3 system will have, the Eastport Study Group reported sensor measurements and the processing of that data in an area of the size of the C2 system environment might require updating the current situation every 10 milli-seconds or so. This is exceptionally fast, however, it is well within today's computer technology and processing capabilitities. [Ref. 2: p. 24]

Communication links and associated equipment would have to exist for passing of data and information between entities and for control purposes. These would include links between the surveillance system and the command center, the

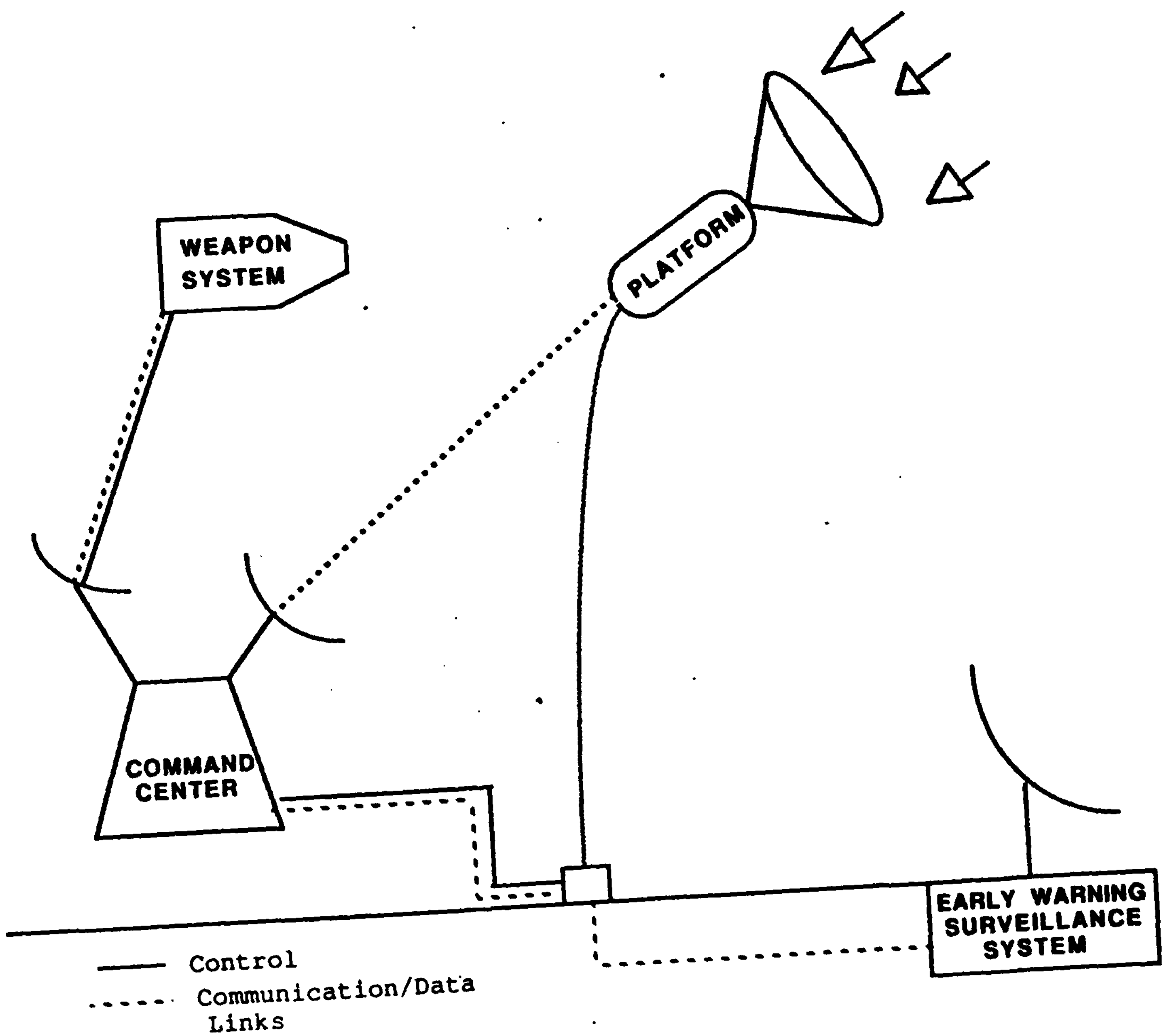


Figure 5.2 Single Layer Command and Control System - PMP Concept.

command center and the launching system, the discriminator platform and the command center, the command center and the weapon system, and possibly the discriminator platform and the weapon system.

c. Structure

Identifying the "Structure" of this C2 system is another important step in bounding the system. Structure is the arrangement and interrelationships of the physical entities, standard operating procedures, information patterns and concept of operations such that command of operations and functional representations are established. For this system, structure may be reflected by information flow.

The surveillance, pop-up, and weapon system and the command center and their interrelationships are also shown in Figure 5.2 . The solid lines represent control lines while the dotted lines show connectivity through information and communication flow patterns between the physical entities. Information of missile trajectories, possible impact points and missile flight time would be needed by the launching system of the discriminator platform. This would be used to determine the launch angle of the platform, the trajectory the platform should follow, and the launch time of the platform so incoming targets can be acquired by the platform. Detailed tracking files would be essential information needed by the command center from the discrimnator platform for threat assessment, prioritization of targets or weapon allocation. The weapon system would be useless without the detailed tracking files and state vector data used by the command center. This data may either be sent directly from the discrimination platform or be passed to the command center and then up to the weapon platform.

The surveillance system may be operated and controlled by the command center of the C2 system described, or by a separate command facility altogether. Although the command center in this C2 system may have the multi-role of being the command facility of the surveillance system, the "pop-up" platform and its launching system, and the weapon system, this analysis will limit the role of the command center's responsibility to the pop-up and the weapon system. It is for this reason that no solid line connects the surveillance system with the command center but one does connect the launching platform with the command center.

The command center will have limited control over the launching of the "pop-up" platform and firing of the weapon system. The commander of the command center is the "man-in-the-loop" of this C2 system. The intial approach to this C2

system is to have the system operate autonomously, if needed, with little to no guidance or direction by the commander. However, man must be able to control the system to prevent accidental launching or firing of systems. A way this could be incorporated is to allow the commander to have direct control of the launching of the pop-up platform and the firing of weapons. The commander may prevent the launching of the platform or the firing of the weapon system, or have the system run autonomously with minimum human interaction. In otherwords, the commander may override the entire system by preventing the systems from completing their functions, like detection, threat assessment, or fire/weapon control.

If the C2 system is to operate with little or no human intervention, the pop-up platform, weapon system and command center must be designed to operate autonomously. This will require the passing of information between the systems for total coordination. Direct data relay channels must be established between the surveillance system to the launching platform and the discriminator platform to the command center and the weapon system for transmission of data. The data paths are shown by the dotted lines connecting those entities. The "pop-up" platform will receive target information and data from the surveillance system and use that data for launching purposes. This data and information might include the types, state vectors, velocities, launch points, and initial predicted impact points of each target, the number of targets, and time of flight for each target. The dedicated discrimination platform is being designed not only to discriminate the types of targets, but also to track the targets for use by the weapon system.

The detailed tracking data of each reentry vehicle in the area must be sent to the command center for management and allocation of weapon release. This data will be more defined than that data sent to the platform system from the surveillance system. It might include state vectors, classification, velocities, and time to impact of each tracked object, and any other pertinent data required to maximize weapon allocation and ultimately, the interception of the incoming targets by the weapon. A dotted line between the sensor and the command center represents this connection. In addition, if a link is established between the discriminator platform and the weapon system, the same tracking information may also be sent to the weapon system. Therefore, the command center and the weapon system will be receiving the same tracking data at approximately the same time. This will save valuable processing time required if the information were to follow a single path of going from the platform to

the command center, and then to the weapon system. Implementation of both of these links may be ideal as back up and for redundancy purposes.

3. Command and Control Process

I can use the the functions identified earlier to develop this system's "C2 process." The functions were discussed in some detail in Chapter 4.3 and won't be reiterated here, however, a short review is necessary. In Chapter 4, several functions were discussed and defined. The functions were:

(a) Warning/Alert
(b) Acquire
(c) Track
(d) Discriminate/Classify
(e) Threat Assessment
(f) Weapon Assignment
(g) Weapon Allocation
(h) Fire/Weapon Control

When the system is completing these functions, either individually or several at a time, the C2 system is considered to be in a dynamic state. Figure 5.3 graphically depicts the ordering of the functions. This particular C2 process will form the execution level C2 process for control of the weapon system.

Due to bounding of the system--one sensor, one weapon system and one command center--the WEAPON ASSIGNMENT function has been deleted from the C2 loop for this analysis. WEAPON ASSIGNMENT is the function that considers the best option of available weapon systems and tasks a weapon system to a specific target. Within this C2 system, only one weapon system is being considered, so assignment of a weapon system to a target is not required. During the WEAPON ALLOCATION function, the capabilities of the weapon will be evaluated and, if correct conditions exist, individual weapons will be paired to a target.

Before continuing, a quick review of the C2 Process Model will explain the relationships I will develop in mapping the functions to the Model. The C2 process model (Figure &cmm) was described in Chapter 2. In short, SENSE is the extracting of signals from the environment. PROCESS and ASSESS are the functions which act upon those signals to attempt to extract meaning about the intentions and disposition of the environment. Alternative courses of actions are developed (GENERATE function), one preferred alternative is selected (SELECT function) and the details

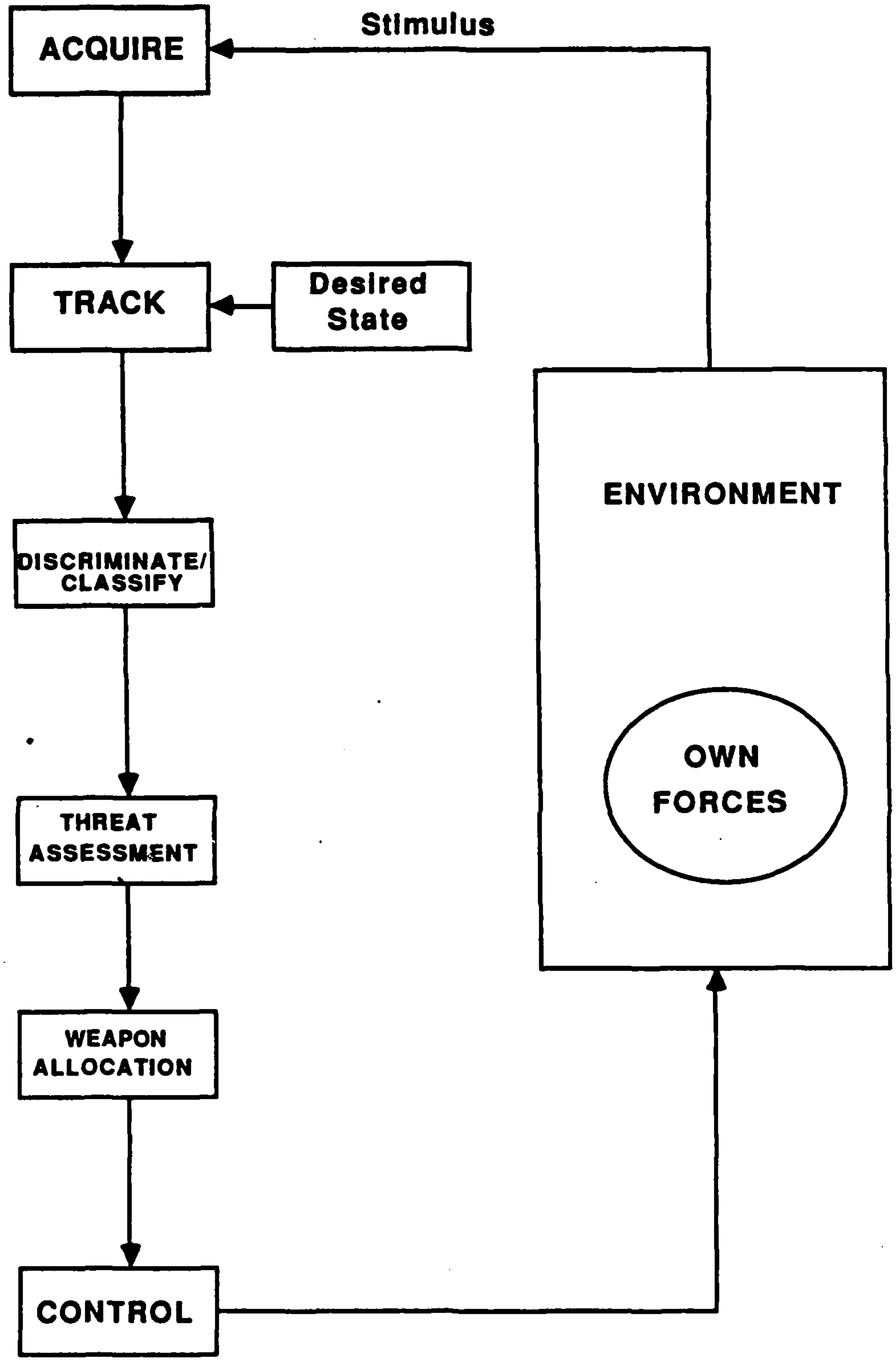


Figure 5.3 BM/C3 C2 Process.

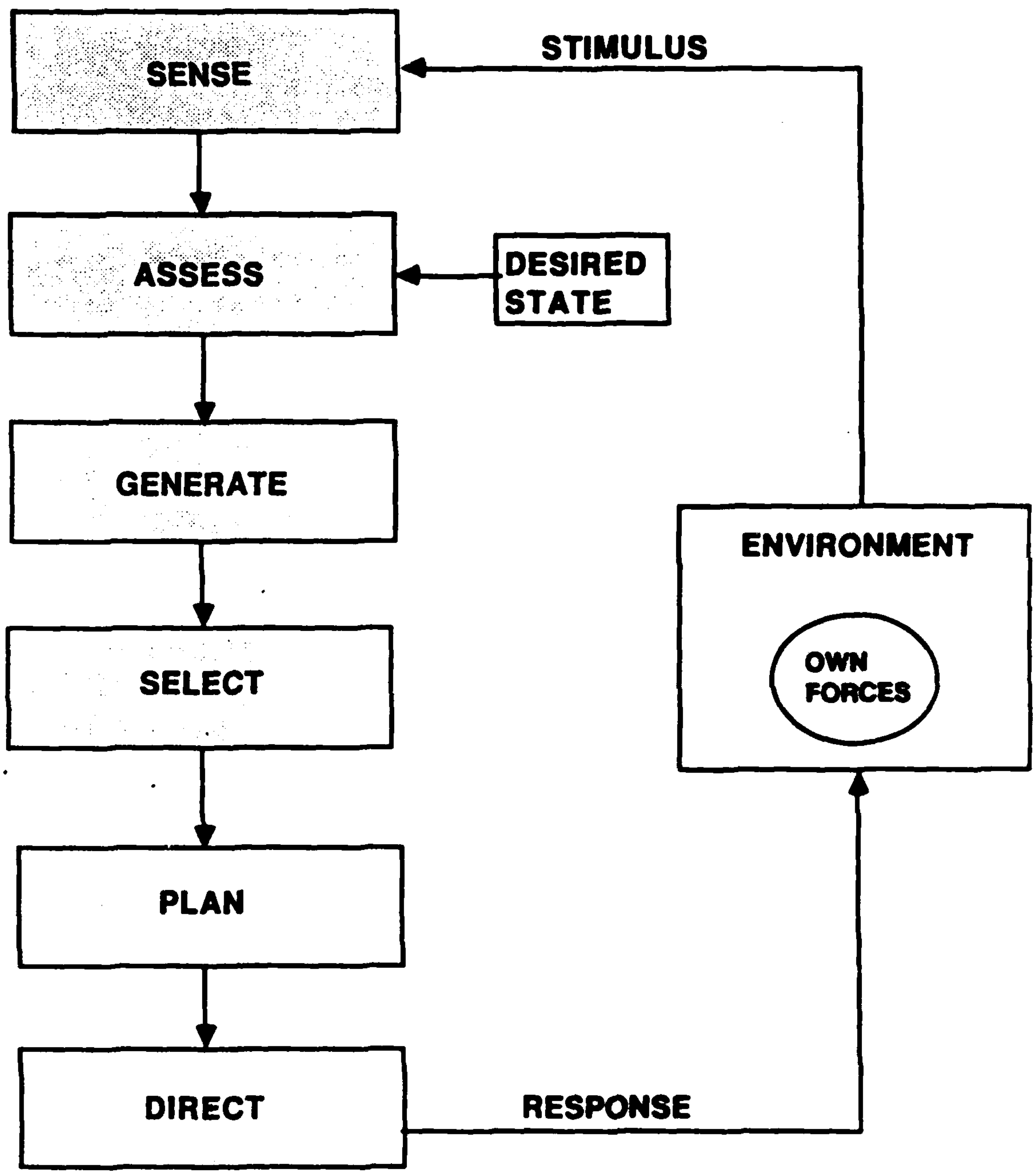


Figure 5.4 Command and Control Process Model.

necessary to execute the selected course of action are identified and developed (PLAN function). Finally, the DIRECT function distributes the decisions to the forces.

At this point, I'm ready to relate the command and control process of this system to the Conceptual C2 Process Model. A mapping between these two processes is illustrated in Figure 5.5 . A listing of the relationships is presented below:

(a) SENSE corresponds to ACQUIRE

(b) PROCESS corresponds to TRACK and DISCRIMINATE/CLASSIFY

(c) ASSESS corresponds to THREAT ASSESSMENT

(d) GENERATE/SELECT corresponds to ALLOCATE WEAPON

(e) DIRECT corresponds to FIRE/WEAPON CONTROL

Major Gandee stated, "The PLAN function has been eliminated because it does not correspond to this level of the C2 system" in his analysis of the air defense C2 problem. This is also applicable to this C2 system. The Plan will be set by a higher level C2 process where the decision maker at that level must make trade-offs on priorities and resources and consider strategies which will support or coordinate with other warfighting missions. For example, Rules of Engagements (ROEs) might state that reentry vehicles directed towards any missile silo must be sought after and intercepted before those directed towards C3 assets or those directed towards major cities. This plan would be injected into the battle management aspect of the command center of the C2 system to allocate specific weapons to prioritized targets.

The C2 process just described is an execution level C2 process which directly controls defense resources. This C2 process is designed to operate independently in accordance with higher echelon priorities.

4. Integration of Statics and Dynamics

The fourth step is to integrate the three dimensions of the C2 system--physical entities, structure and the C2 process. In reviewing the C2 process, the hierarchal structure is defined. The weapon system can not perform its functions without tracking data from the command center or the sensor system and the approval of operations by the commander of the command center. The discriminator platform can not perform its functions of tracking or discriminating targets if it isn't launched. The pop-up system won't be launched unless a surveillance system indicates a possible ballistic threat is within its area and, again, the commander's approval to take such action. In general, data, in the form of commands and information, must be past between the physical entities before functions can be completed. Although the data

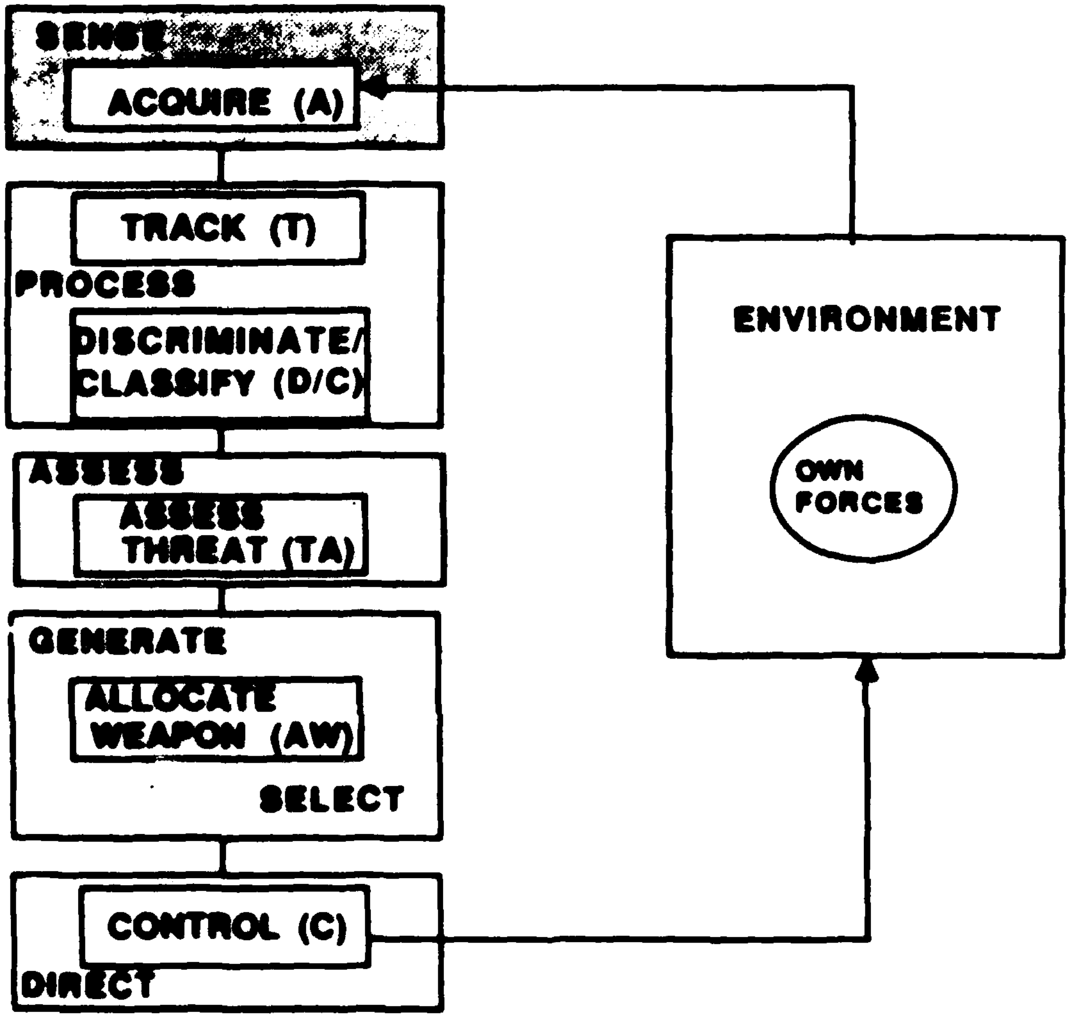


Figure 5.5 Mapping Between Processes.

composition is beyond the scope of this analysis, the functions can be performed by the entities if the data is timely, accurate and complete.

Thus, the functions of the C2 process can be matched to the physical entities. The discriminator platform performs the DETECT and PROCESS functions. The command center completes the ASSESS, GENERATE, SELECT and DIRECT functions. Lastly, the weapons system is our "force", which interacts with the environment. See Figure 5.6 .

5. Identification of Measures

a. Overview

Specifying the measures necessary to address the BM/C3 system is the intent of this section. Four types of measures are possible. Two are measured inside the boundary of the C2 system, i.e., dimensional parameters and measure of performances, while the other two are measured outside the boundary of the C2 system, i.e., measure of C2 effectiveness and measure of force effectiveness. I will identify measures of force effectiveness, effectiveness and performance for the C2 system being analyzed.

b. Measures of Force Effectiveness (MOFEs)

At every level there is at least one "measure" which indicates how well a system is doing. The effect of the last C2 process function, FIRE/WEAPON CONTROL, can be a measure of force effectiveness by looking at the battle outcome of an attack. This could be measured by "the number of targets that were engaged per unit of time." However, that measure does not include the weapon's probability of kill. Even if a weapon intercepts a target, the measure wouldn't reveal the number of weapons that failed to destroy the target, as compared to those that succeeded in destroying the target. Nor would this measure indicate whether the right targets were intercepted. So a better measure of force effectiveness might include:

(a) Expected percent of threat value destroyed by available weapons; or

(b) Expected percent of threat value protected by available weapons

These two measures of force effectiveness of the system relate to the accomplishment of the mission.

c. Measures of Effectiveness (MOEs)

In the application of the MCES to the air defense C2 problem, Major Gandee stated:

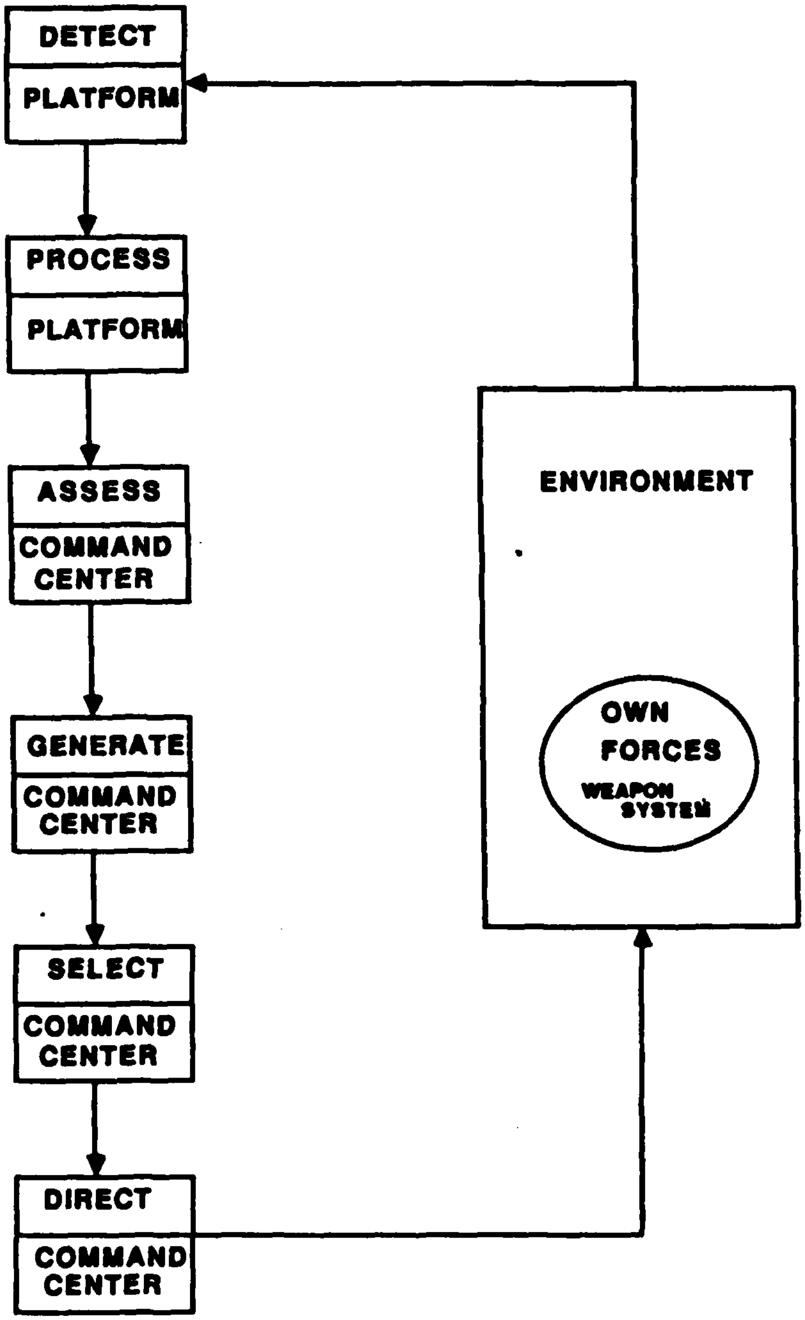


Figure 5.6 Functions Corresponding to Physical Entities.

A good starting point for developing measures is to look at the C2 Process. The C2 process is a group of functions which are required to control the force within the environment. If one can measure the capabilities to do all the functions, this represents a measure of the ability to control the force within the environment. Thus, the ability to perform the entire C2 process is measured by a set of MOEs for the C2 system of interest."

[Ref. 7: p. 66]

This is the approach I'm taking to identify measures of effectiveness. Two important aspects of this system became apparent in looking at the C2 process, and if measured, could determine the effectiveness of the system. One was the "timeliness" at which one could proceed through the functions of the C2 process. Once the system has received a stimulus, such as a command to launch the pop-up platform from the command center, no response can be delivered before a necessary amount of time has elapsed. In other words, each function will experience some time delay. The total of those time delays must not be so long that the target is no longer within the system's "window of opportunity". The window of opportunity is defined as the moment the reentry vehicle is within the area of coverage, or range of the weapon system to the moment when the vehicle leaves the weapon's area of coverage. The C2 system must complete its C2 process in such time that the weapon can engage the threatening reentry vehicle before it either leaves the outer limits of the weapon range or impacts upon the Earth. To maximize the effectiveness of a C2 system, one would minimize the time delays to complete the C2 process.

Two types of time delays are present: time delays in the completion of each function, such as detecting, tracking, discriminating, or classifying, the reentry vehicles and threat assessments, as examples; and time delays in information transfer between entities. Information transfer delays are associated with sending specific types of information between specific entities, such as finished tracks from the sensor to the command center. These can be estimated by examining the messages and available times between each entity. With these two time delays in mind, the first measure of effectiveness is:

Time between the moment the C2 system receives a stimulus from the command center or surveillance system that the platform should be launched, to the moment it can deliver a response to this stimulus by launching a specific weapon to intercept the threatening target.

The ability of the system to act upon a stimulus represents the "timeliness" of the system. This measure is quantifiable and could be calculated by summing the times of the individual functions of the C2 process. This implies that the time delays that contribute to this "expected time" are a function of the entities (software, hardware, subsystems, communication mediums, etc.) that data must pass through and between to complete the C2 process.

It may not be sufficient that this C2 system is fast enough, in order for good, preplanned and automated decisions be made, the C2 system must provide "accurate" information and support. Quality of information is particularly important in two functions: the ASSESSMENT and WEAPON ALLOCATION functions. The ASSESSMENT function must accurately estimate/predict a number of unknowns such as missile launch points, target impact points and possible interception points, and classification of the target type. The WEAPON ALLOCATION function relies on quality of data for proper resource tasking. This is an extremely critical function because it attempts to optimize interceptor deployment. Data quality has a direct impact of optimizing intial target engagement sequencing and weapon/threat matches in space and time.

In addition to the MOEs that evaluate the ability to perform the C2 process, there are other effectiveness measures that relate the physical entities of the C2 system to the overall system effectiveness. These include system survivability and availability. Both of these measures would represent a probability that the system will perform its intended function for a specific interval under stated conditions. Since these terms have many meanings, the following definitions seem appropriate for this study:

(a) Availability - the system can provide continuous performance at any time in a benign environment. (Ref)

(b) Survivability - the system can provide continuous performance in a hostile environment while under attack. (Ref)

Availability deals with the reliability and maintainability aspects of the system. Reliability measures would reflect the probability of uninterrupted performance during deployment, mean time between failure, the dependability or reliability of the sensor, weapon systems, command center and the software in each of the these systems and the reliability of the communication links imbedded in the C2 system. Maintainability measures would address issues such as mean time to repair and the probability of uninterrupted performance during maintenance, replacement or

enhancements. A measure of availability would be a coupling of both reliability and maintainability.

While availability deals with maintainability and reliability, survivability deals with the system's resistance to elements of threat. A possible measure might be "probability surviving an attack on the C2 system". These would include vulnerability aspects such as attacks or countermeasure activities directed towards the entities or any communication or data links connecting the entities of the system. In addition, self protection capabilities, such as hardening, shielding, dispersion and silent spares for the platform and the weapon system, physical and operational security for the command center, and the ability to detect hostile activity directed towards the defense assets would be of concerned to the decision maker. Taking into account such survivability and availability aspects, representative measures would indicate the system's ability to continue to operate after an attempt to disable it. Possible availability and survivability measures are listed in Table 8 .

TABLE 8

AVAILABILITY AND SURVIVABILITY MEASURES

* Probability of sensor availability
* Probability of weapon system availability
* Probability of software availability on sensor system
* Mean time to failure and mean time to repair
* Probability of uninterrupted performance during deployment
* Probability of uninterrupted performance during maintenance

d. Measure of Performance (MOPs)

Within the C2 boundary, individual C2 functions must be performed to complete the C2 process for any given attack. For a command and control system such as the one being analyzed, results of the functions could be considered possible MOPs. Each of these measures, identified individually by functions, contribute to the overall MOE. The possible measures are listed in Tables 9 and 10 by the entities that complete the functions. Table 9 lists the MOPs for the ACQUIRE, TRACK, and

TABLE 9

MEASURES OF PERFORMANCE - PLATFORM

ACQUIRE

- Time from launch to initial detection of object
- Probability of detecting an object given an object was present
- Probability of not detecting an object that was present
- Probability of false detection (detecting an "target" that was not present, e.g. sun, star)
- Processing rate to initialize detected object
- Percentage of targets detected

TRACK

- Time required to develop track file
- Track file update rate
- Percent error in accuracy of state vector/track file

DISCRIMINATE/CLASSIFY

- Time from target acquisition to threat designation
- Probability of correctly discriminating a decoy given a decoy target
- Probability of discriminating a RV given a decoy target
- Probability of correctly discriminating a RV given a RV target
- Probability of discriminating a decoy given a RV target
- Processing rate to discriminate a target given a detection
- Processing rate to classify a live warhead
- Percent of targets discriminated given tracking files
- Probability of accurately specifying impact point prediction
- Percent error of impact point predictions and actual impact point
- Probability of correctly classifying a reentry vehicle

TABLE 10

MEASURES OF PERFORMANCE - COMMAND CENTER

ASSESS THREAT

Time to determine the threat value given response plan

Probablity of correctly determining threat value given plan response

Probability of correctly prioritizing threat value given response plan

Processing time to determine the threat value given response plan

WEAPON ALLOCATION

Time to pair individual weapon with target

Probability of correctly prioritizing target given response plan

Probability of allocating weapons given prioritized target data

Probability of overkill - shooting the same target twice

FIRE/WEAPON CONTROL

Time for engagement authorization to weapon firing on given target

Percent error in state vector/track file handover to weapon system

DISCRIMINATE/CLASSIFY functions completed on the platform. Table 10 lists the MOPs for the ASSESS, WEAPON ALLOCATION and FIRE/WEAPON CONTROL functions completed by the command center. Note that each function has a time measure associated with its function. In order to complete each function, a delay in time must occur. These "time" MOPs would be used in quantifying the overall time MOE. The other MOPs represent the accuracy with which each function complete its task or the probability of attempting the task given the previous function was completed. Many of the accuracy measures are stated by the "percent error" of correctly doing a task or the probability of doing the task at all.

This section would not be complete without relating the MOPs to the MOEs. Theoretically, functional performances should be combined to get the overall

effectiveness measures. To explain the relationships between MOPs to the MOEs, the "timeliness" MOE will be reviewed.

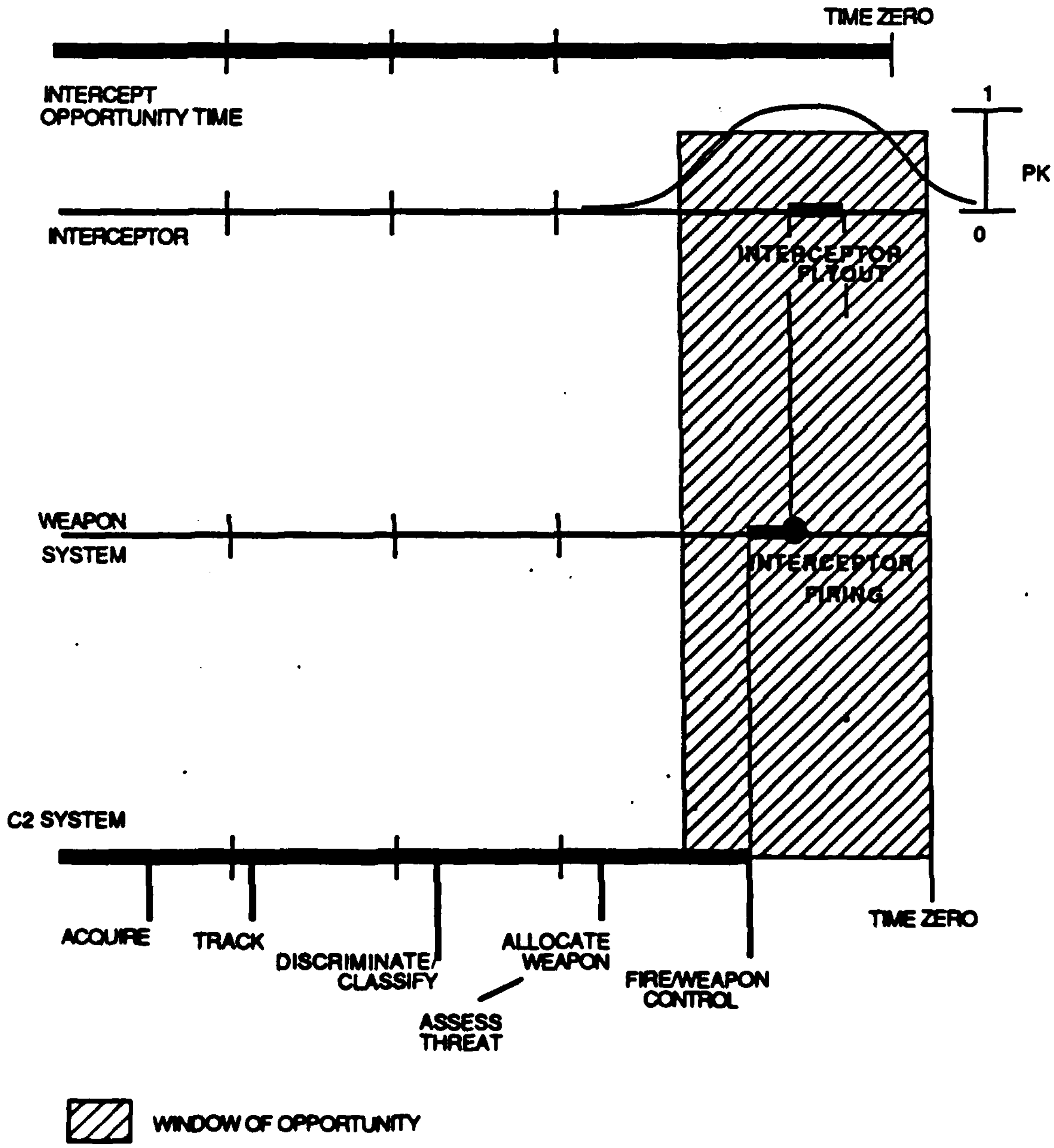


Figure 5.7 Timeline Analysis to Complete the C2 Process.

Time was based on how fast one could react to a stimulus. If all the individual functional delay times were added, the summation would be a represent the

time to complete the C2 process. This value would be useful in evaluating whether the system is capable of acting in timely manner. "Timely", in this case, means that the decision to act on a stimulus must be done within a time frame such that the target is within the weapon's engagement zone. This can be seen by the timeline in Figure 5.7 . The heavy dark line at the bottom represents the time to complete each of the individual functions of the C2 process. The distances representing time are strictly for graphical purposes only and are not to imply that one function will take longer or less time than another. The top dark line indicated the interceptor opportunity time. This represents the available time the interceptor can engage the target, which depends on weapon system and target positions as well as the target course and the interceptor course. This line could be very short if the range of the interceptor is short or if the distance between the weapon system and the target is long. The control function on the C2 time line extends to a point where the weapon system releases its kill vehicle, which signifies that the C2 process is complete. If a weapon system is fired, the weapon will flyout and, hopefully, intercept the target. If interception was completed, it would be at the point of the far right side of the "interceptor flyout" heavy dark line.

The measures identified in this section are not conclusive. More measures could be identified and defined. The intent was to introduce the concept of identifying measures oriented towards the functional aspects of the C2 system, such as time and accuracy, and those measures directed towards the entities of the system, such as availability and survivability.

6. Data Generation

At this point, values for the measures or variables identified in the previous section must be generated. Several types of data generators are available. These could include an experiment to test the PMP system concept, computer simulations to model the enemy's threat and the performance of the functions, entities and C2 process accomplished by the C2 system, or lastly, subjective judgements based on the experience and knowledge of the designers or analysts.

One possible method to generate data for the C2 system being analyzed would be to subject the platform's sensors, computer processing capabilities, and battle management functions to a simulated Soviet attack. The simulation could include using available resources at the Sandia National Laboratory. The sensors would operate in a simulated real-time environment. Data from the sensors would be processed for tracking and discrimination purposes. The representative battle manager

would use the resultant data for fire control and weapon allocation. Throughout the simulation, data would be recorded for analysis of the system. The simulation could stop short of integrating the weapon system because the weapon's performance could be tested separately with the data produced by this experiment as the input to a weapons test. The intent of the simulation would be to generate values for the previously defined evaluation measures and to test the technologies of the system.

At this stage of the development of the platform manager by Sandia National Labs, computational models are being used throughout the design of the system to estimate the technological cababilities and operational aspects of the platforms sensors and the onboard manager. An example of this is Dr. Richard Wheeler's efforts to analyze the different methods or algorithms the charged particle beam can be sequenced or pointed to discriminated the randomly scattered targets. These generate data through computational analysis.

For BM/C3 systems, there are significant problems with availability of data. Since the program is in the conceptual phase and nothing has been set in concrete, certain data, like operational characteristics and performance standards are unavailable for analysis purposes. Under these circumstances, SDIO has initiated and supported the SDI National Test Bed (NTB). The intent of the NTB was to have designated laboratories with the analytical tools and resources available to model and test BM/C3 systems and subsystems capabilities and the overall force effectiveness of such systems. Two vital purposes have been identified for the NTB:

1. Demonstrate and Evaluate
   - SDI BM/C3 Architectures
   - Key Defensive Technologies

2. Support an Informal Full Scale Development (FSD) Decision in the Early 1990's (Ref 2)

Figure 5.8 shows the proposed NTB. The National Test Facility (NTF) will be the "headquarters" of the NTB and will be located at the Consolidated Space Operations Center (CSOC) at Falcon Air Station, twenty miles east of Colorado Springs, Colorado. Facilities at different locations will be connected to it via computer communication links. These connected facilities will include White Sands National Laboratory (WSNL), Vanderburg Air Force Base (VAFB) and Kirkland Air Force Base (KAFB). The development phase of the NTB doesn't begin until later this year (FY87) with expected completion in FY92.

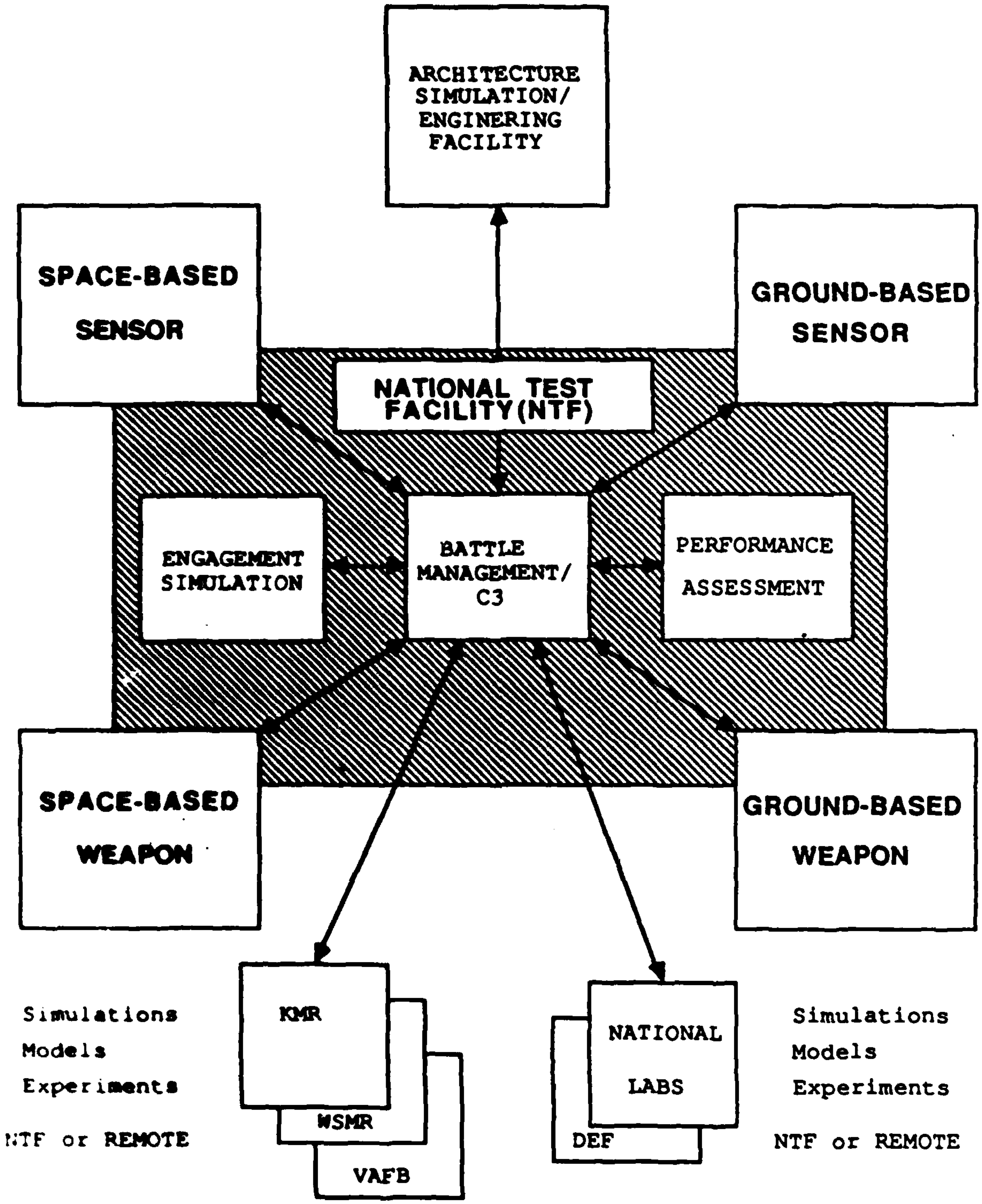


Figure 5.8 SDI National Test Bed.

The NTB could be the data generator for evaluating the PMP concept and its associated BM/C3 architecture. The testbed will subject proposed architectures to various enviromental conditions expected during the launching of USSR ballistic missiles while analyzing measurable variables in an attempt to recognize important issues in evaluating a C2 system. Experimental designs and simulation models will address the measures stated for the test at hand.

The first tests the NTB will run will be smaller simulation models that have compatible software/hardware capabilities. This may be appropriate for the beginnings of the PMP testing and experimentation.

7. **Data Aggregation**

As a final step, meanings must be assigned to the values of the measures to identify what this says about our system. Some measures, when applied throughout the C2 process, are aggregable measures. For example, an overall reaction time, or response time, may equal the time for the sensor to detect a target added to the time for the platform manager to assess the targets threat status, added to other time intervals to get an overall time delay value. This time delay must not be so long that the weapon system can't engage the target before it detonates or impacts upon the Earth. If this were the case, the system is a failure in an operational capacity and efforts would have to be directed to reduce the time delay or reconsider the possibility of developing a successful BM/C3 system.

In turn, this would have a direct impact on the measure of force effectiveness. If the reaction time of the C2 system is too slow, the weapon system wouldn't be able to destroy the target. Then the measure of threat value protected by the C2 system would be minimal, reflecting the ineffectiveness of the forces of the entire system.

The results of the experiments could also be used to determine the key issues directly effecting the measures used to evaluate the command and control of a SDI system. By aggregating the data, additional factors might become relevant and interact with the system in such a way that those, too, might need to be analyzed individually. New insights and issues once-thought irrelevant might play an important role in determining the effectiveness of the BM/C3 architecture and its role in the SDI mission.

C. CHAPTER SUMMARY

This chapter applies the MCES methodology to a SDI C2 system designed for the midcourse phase of a trajectory. The system was analyzed according to the methodology's seven module step through process. Specifying the measures to evaluate the system was the main objective of this methodology. Several measures, such as timeliness, accuracy, survivability and availability, were identified to indicate the effectiveness of the system, while measures of performance were selected to evaluate the accomplishment of the individual functions of the C2 process. In turn, these were related to the effectiveness measures.

VI. SUMMARY/CONCLUSION

A. OVERVIEW

This thesis addresses the need for evaluation measures for BM/C3 systems of the SDI project. Without such measures, any assessment of a command and control system would be inaccurate and incomplete. A specific analysis structure, the Modular Command and Control Evaluation Structure (MCES) was used as a guide to identify possible measures to be used to evaluate a specific C2 system being researched and developed by Sandia National Laboratories, called the Platform Manager Program. I'll first start with the MCES by looking at how the MCES has been applied to this C2 system.

B. APPLICATION OF THE MCES EVALUATION STRUCTURE

The MCES is a tool to be used by staff officers tasked with evaluating alternative C2 architectures. The intent behind the methodology is to assess the effectiveness of a specific system through a detailed evaluation of its C2/C3 architecture. Architecture has been defined as "an integrated set of systems whose physical entities, structure and functionality are coherently related." Sharing this common terminology allows direct application of the MCES methodology to actual and proposed architecture problems.

Dr. Sweet has written several manuals explaining her efforts in evolving the MCES methodology to what it is today. Much of her work was combined in the this thesis to describe the methodology and subsequently, used in this SDI BM/C3 application effort.

At the SDI MCES/MOE Workshop, the BM/C3 Systems Working Group applied the MCES to develop measures to be used in the evaluation of the effectiveness of alternative BM/C3 architectures. Although the Working Group identified and developed several generic measures, there was evidence that in order to solve the dilemma of which systems should be incorporated into the overall BM/C3 architecture, one would have to identify measures to evaluate BM/C3 subsystems, generate data to put a comparison value on those measures and then aggregate the data to determine the effectiveness of each BM/C3 architecture. The Workshop provided the framework behind this thesis, however, instead of looking at the full spectrum of the SDI BM/C3 architecture, I narrowed my views by looking at a lower level C2 system with few

subsystems. After speaking with the developers of the PMP concept at the Sandia National Laboratories, I set off to identify lower level system measures.

I extensively used Major Pat Gandee's thesis entitled, "Evaluation Methodology for Air Defense Command and Control System" in proceeding through the modules of the MCES. In many aspects, I felt several of the functions accomplished by the air defense C2 system were comparable to the functions accomplished by the ballistic missile defense C2 system. Many of the definitions used in his thesis were incorporated into this thesis , however, all of them were tailored to fit the SDI C2 system.

C. MEASURES CONCEPT REVIEW

The MCES descriptions of the MOP, MOE, and MOFE, and the concept of the relationships between these measures and the boundaries of the system was used in the identification and development of the measures. The guidelines provided by the MCES were such that measures of performance were measured inside the boundary of the C2 system while the measures of effectiveness and force effectiveness were outside the boundary of the system.

This thesis interpreted the boundaries of the C2 system in terms of the system's physical entites, such as weapon and sensor system and the command center and the C2 process with the individual functions it would perform. MOPs would measure the performance of the individual functions of the C2 process through the identification of the entity that is accomplishing that function. MOEs would measure the capability to do all of the functions as one. MOEs for the functional aspects of the system include timeliness and accuracy while MOEs for the entities related to the survivability and reliability aspects of the system.

D. SYSTEM BOUNDING REVIEW

I had restricted the number of subsystems in this C2 system such that only one command level was being represented. Although technological constraints might restrict the initial deployment of the SDI system to a very limited number of weapon and sensor systems, by no means will the SDI system remain at one command level. Many of the topics discussed throughout this document addressed several generic C2 system level issues but at a lower level. The integration of different levels is what makes the SDI BM/C3 architecture problem so vast. This thesis could easily be expanded upon to further address evaluation measures at either a different level or a combination and interaction between levels.

One example would be to expand the boundaries to include not just one platform system and one weapon system under the control of one command center, for the interception of reentry vehicles during the late mid-course phase, as was the approach of this thesis, but to include several platforms and weapons systems for the same phase. Another would be to increase the boundaries to include not only those systems that are in direct support of the midcourse phase, but include those systems that will be designed for the boost and terminal phases. Its obvious that those system would have to share intelligence data, accurate target information and coordinate activities in a timely manner to be effective as a system in destroying threatening warheads.

The application of the MCES to the PMP concept as a C2 system has been relatively straight forward, however, not complete. There are other issues that must be addressed by the designers of this system before a final evaluation plan can be established for this system. One major issue is the possibility of the pop-up system having multiple staring and/or multiple LADAR sensor systems on board the platform. This wouldn't change the measures of effectiveness I proposed to evaluate the system, however, this could directly effect the performance of the system and most probably the effectiveness of the system.

This all leads back to the degree of autonomy the C2 systems of the BM/C3 architecture should have. If the autonomous C2 systems could be more effective in protecting U.S. assets then those systems with a "man-in-the-loop," then the autonomous systems should be considered for integration into the BM/C3 architecture. Less communication links for operations, control and direction would be required and the decision maker would be onboard the platform itself. This would greatly enhance the survivability aspects of the C2 system.

E. CHAPTER SUMMARY

This chapter has recapped the proceedings of the this thesis and has recaptured the magnitude of the SDI BM/C3 architecture problem. No such "SDI" system exists yet, however, efforts continue to not only make the system deployable, but to make it the most effective system envisioned.

APPENDIX A
PHASES OF A TYPICAL TRAJECTORY

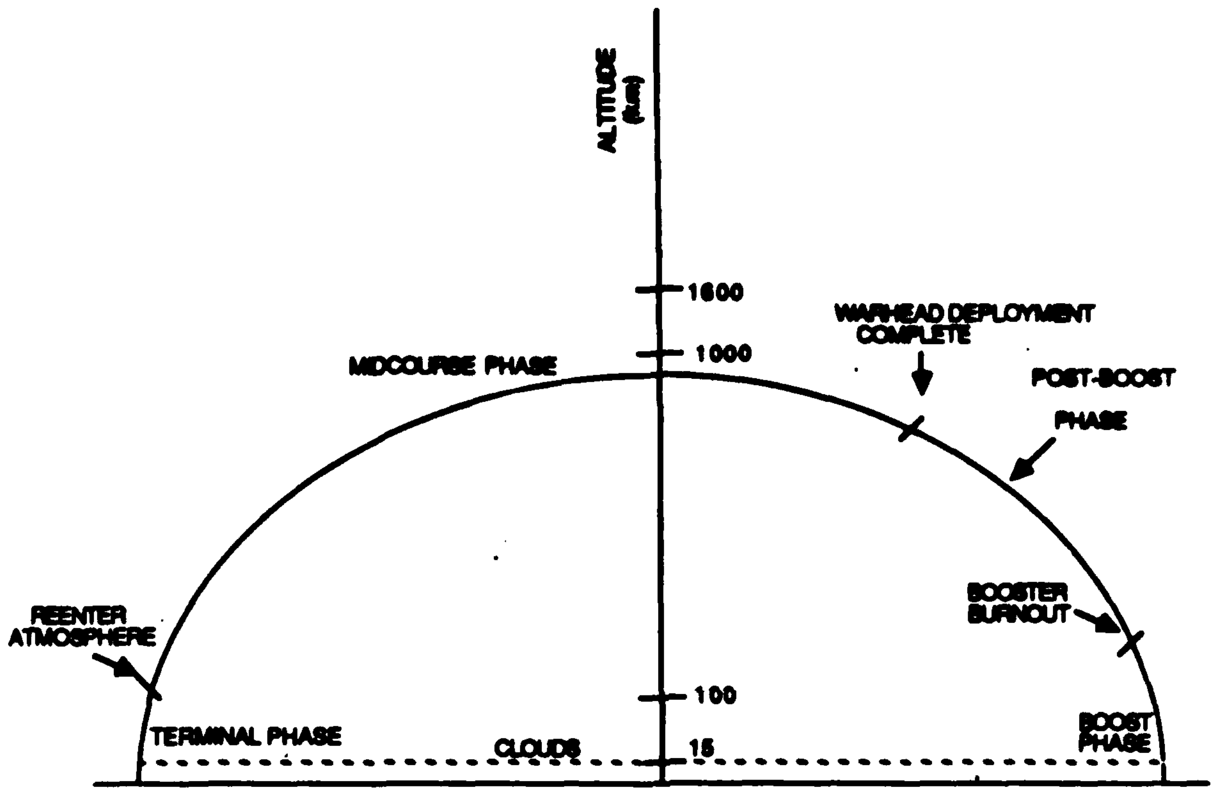


Figure A.1 Three Phase Ballistic Missile Trajectory.

A review of the physical characteristics of the strategic defense problem may be needed to define the dimensions of a typical trajectory. For this document, the trajectory of the missile will be divided into three dimensions, or phases. They are called the boost, mid-course and terminal phases. The following paragraphs define the dimensions of these areas, as used by most analysts in the SDI community. See Figure A.1 .

The first phase is the BOOST phase, which will last from 2.5 to 6 minutes [Ref. 1: p. V-5]. In this phase, the first- and second-stage engines of the missile are burning and producing intense infrared radiation that has distinctive spectral

signatures. Although this phase only lasts a few seconds, research is addressing the technological challenge of intercepting the ballistic missiles through the detection of the emitted radiation. When the boost phase is completed, the missile releases a bus containing on the order of 10 warheads and enemy "penetration aids," each into a slightly different ballistic trajectory. Many analysts view this bus deployment as a separate phase, commonly referred to as the POST-BOOST, or BUS DEPLOYMENT, phase. This distinction is not needed for this document and will suffice as part of the BOOST phase. Interception of the missile in the boost phase offers the advantage not only of dealing with a larger target than a reentry vehicle, but also of eliminating the many individual targets - reentry vehicles and decoys - that are launched from the bus of a single missile.

During the MID-COURSE phase, the reentry vehicle and decoys follow ballistic trajectories a few hundred kilometers above the atmosphere. This phase lasts anywhere from 6 minutes for SLBMs to 25 minutes for ICBMs [Ref. 1: p. V-5]. During this phase the incoming warhead must be discriminated from decoys. Those reentry vehicles that are not intercepted at this phase will enter the final phase of the trajectory, the terminal phase.

The TERMINAL phase is the final opportunity to detect and intercept the incoming warheads. Upon entry into the Earth's atmosphere, this phase may last from 20 to 60 seconds [Ref. 1: p. V-5]. This is a very dynamic phase for the interception of the vehicles because both reentry vehicle trajectories and signatures may be effected by atmospheric drag.

LIST OF REFERENCES

1. Strategic Defense Initiative Organization, Department of Defense, *Report to the Congress on the Strategic Defense Initiative*, U.S. Government Printing Office, Washington, DC, June 1986.

2. Eastport Study Group, "A Report to the Director Strategic Defense Initiative Organization," proceedings from a summer study, 1985, U.S. Government Printing Office, Washington, DC, December 1985.

3. Athans, Michael, "The Expert Team of Experts Approach to Command and Control (C2) Organizations," *IEEE Control Systems Magazine*, Vol. 2, No. 3, pp. 30-38, September 1982.

4. Sweet, R., *The Modular Command and Control Evaluation Structure (MCES) Application of and Expansion to C3 Architecture Evaluation* proceedings from research by Dr. Ricki Sweet, Naval Postgraduate School, September 1986.

5. Sweet, R., Metersky, M., and Sovereign, M., *Command and Control Evaluation Workshop*, proceedings from Military Operations Research Society C2 MOE Workshop, Naval Postgraduate School, Monterey, California, January 1985.

6. Joint Chiefs of Staff Publication 2.

7. Gandee, Patrick L., *Evaluation Methodology for Air Defense Command and Control System*, M.S. Thesis, Naval Postgraduate School, Monterey, California, March 1986.

8. Sweet, Ricki, *The SDI MCES/MOE Workshop*, proceedings from the SDI MCES/MOE Workshop, Naval Postgraduate School, Monterey, California, December 1986.

9. Strategic Defense Initiative-BM/C3 Working Group for Standards, *Function Decomposition*, SDI Program Office (MD), Electronic Systems Division, Hanscom Air Force Base, Massachusetts, September 1986.

10. Herrick, Samuel, *Astrodynamics: Orbit Determination, Space Navigation, and Celestial Motion*, Vol I, Van Nostrand Reinhold Company, London, England, 1971.

11. Martin, Terry L., *Command, Control and Communication Missions and Organization: A Primer*, M.S. Thesis, Naval Postgraduate School, Monterey, California, March 1984.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Dr. Jay Lawson 4773-c Kahala Ave Honolulu, Hawaii 96816	1
4.	Office of Joint Chiefs of Staff/J6 ATTN: Major Pat Gandee Washington, DC 20301	3
5.	Office of Joint Chiefs of Staff/J6F ATTN: Dr. John Dockery The Pentagon Washington, DC 20301	2
6.	MIT ATTN: Dr. Alexander H. Levis 35-410/LIDS Cambridge, Massachushetts 01239	1
7.	Naval Postgraduate School C3 Academic Group, Code 74 ATTN: Dr. Michael G. Sovereign Monterey, California 93943-5000	2
8.	AFIT/CISK ATTN: Major Harlan Wright-Patterson AFB, OH 45433-6583	1
9.	Sweet Associates, Ltd. ATTN: Dr. Ricki Sweet Post Box 9196 Arlington, Virginia 22209	2
10.	Electronic Systems Division/XR-1 ATTN: Lt. Col. Mervosh Hanscom AFB, Massachusetts 01731	1
11.	Dr. Miriam John Sandia National Laboratory Livermore, California 94550	1
12.	Dr. Larry Brandt Sandia National Laboratory Livermore, California 94550	1
13.	Dr. Richard Wheeler Sandia National Laboratory Livermore, California 94550	1
14.	BMO/ACP ATTN: Captain Kathleen J. O'Regan Norton AFB, California 92409-6468	1

15. Foreign Technology Division/XOQR 1
ATTN: Charles Fugate
Wright-Patterson AFB, Ohio 45433

16. Naval Postgraduate School 2
C3 Academic Group, Code 39
ATTN: Lois Brunner
Monterey, California 93943-5000

17. ATTN: Gail K. Kramer 2
P. O. Box 426
Moffett Field, California 94035

END

7-87

DTIC